Meteorological Case Studies of Turbulence Encounters

Richard Ferris

Outline

- Basis for Investigations
- Data Collection
- Case Studies
  - West Palm Beach, FL (Convective)
  - Wilmington, DE (Convective)
  - Cross City, FL (Convective)
  - Cape Girardeau, MO (CAT)
  - Houston, TX (Inconclusive)
- Conclusions
- Future Work

Basis for Investigation

- Assistance to:
  - National Transportation Safety Board (NTSB)
  - Dryden Flight Research Center (DFRC)
- NTSB
  - Analyses to help determine cause of upsets
- DFRC
  - Flight Operations Quality Assurance (FOQA) data
  - Weather analysis of selected turbulence cases
  - Safeguards taken to prevent unauthorized disclosure

Basis for Investigation

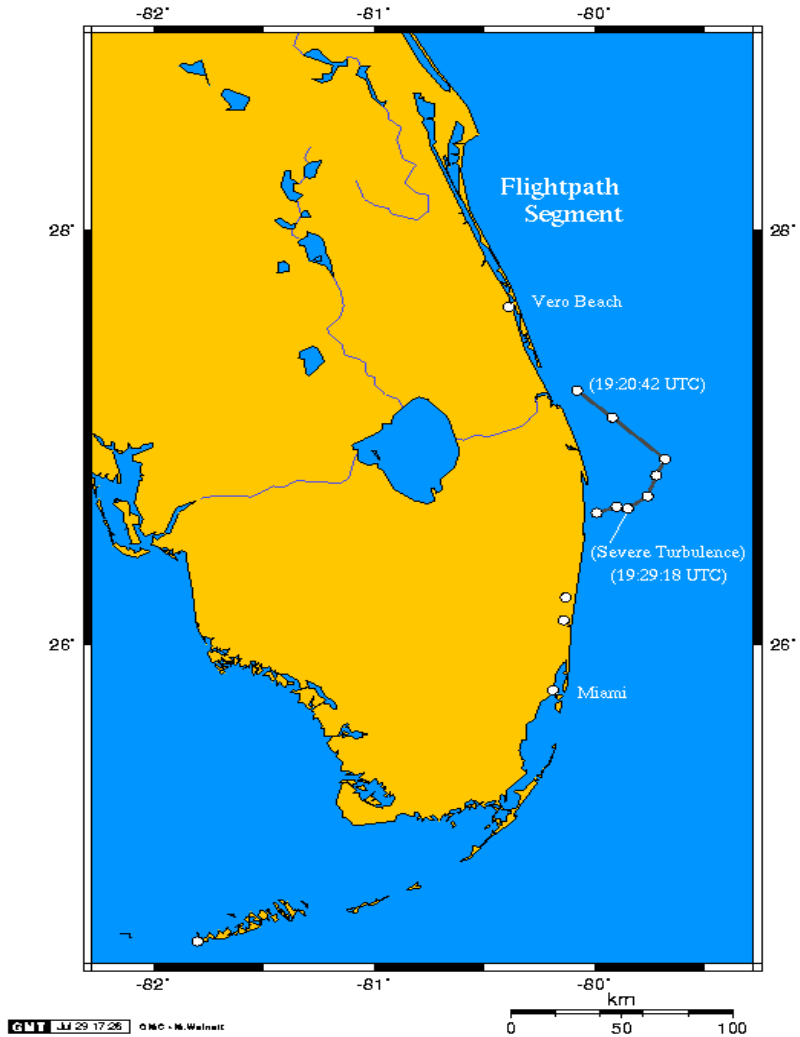
- Flight data recorder data alone will not suffice to determine causality
- Need to understand meteorological phenomena to develop an overall avoidance system
- Results will provide insights into issues that arise in both encounter analysis and development of automated systems
- Unclear if one would have identified operationally significant turbulence without apriori knowledge of upset location

Data Collection

- Mishap locations and flight profiles provided by NTSB and FOQA data
- Weather data obtained from National Climatic Data Center
  - NEXRAD Archive Level II
  - Satellite imagery
  - Upper air charts/soundings
  - Surface charts
- Data processed, generated, and analyzed locally

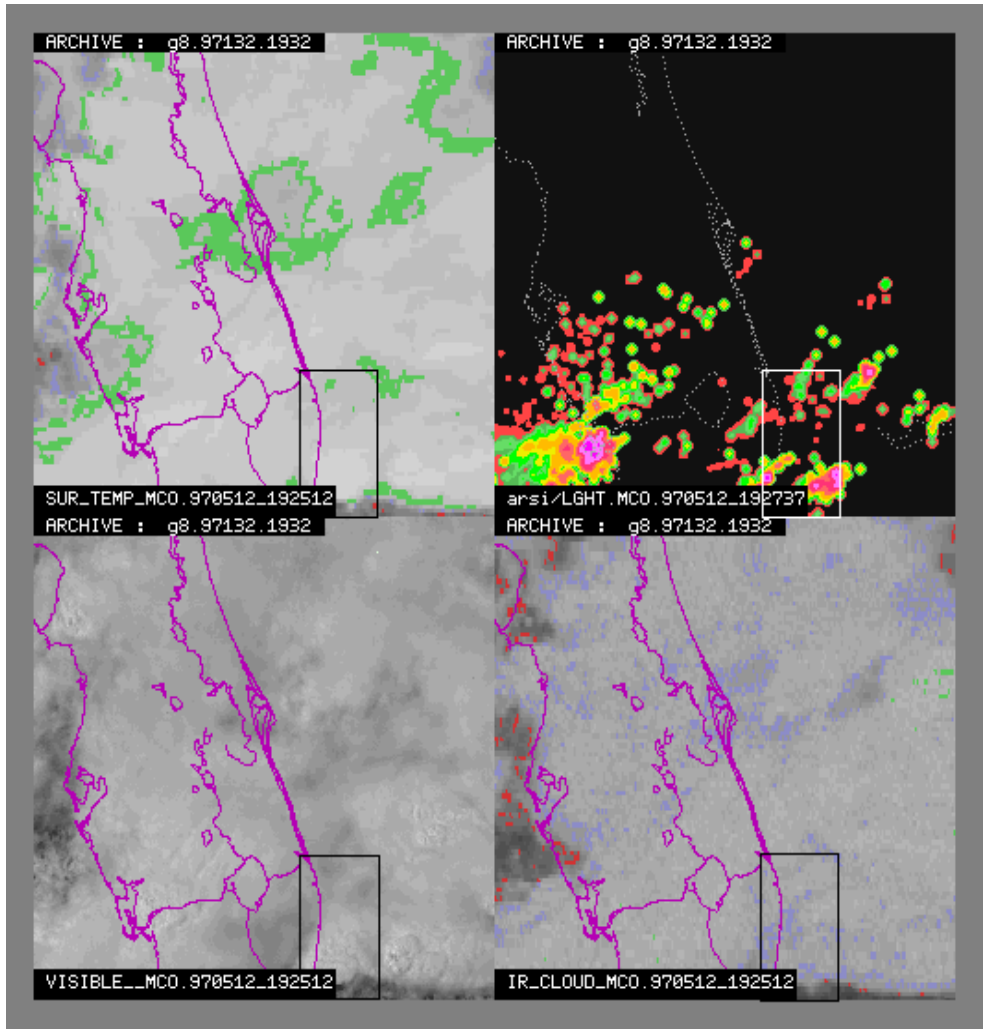
Case Study 1 (NTSB)

- Severe turbulence near West Palm Beach, FL
- One pax seriously injured
- Initially at 16,000 ft
- Loss of over 3000 ft in 30 sec
- Recovered and landed at MIA



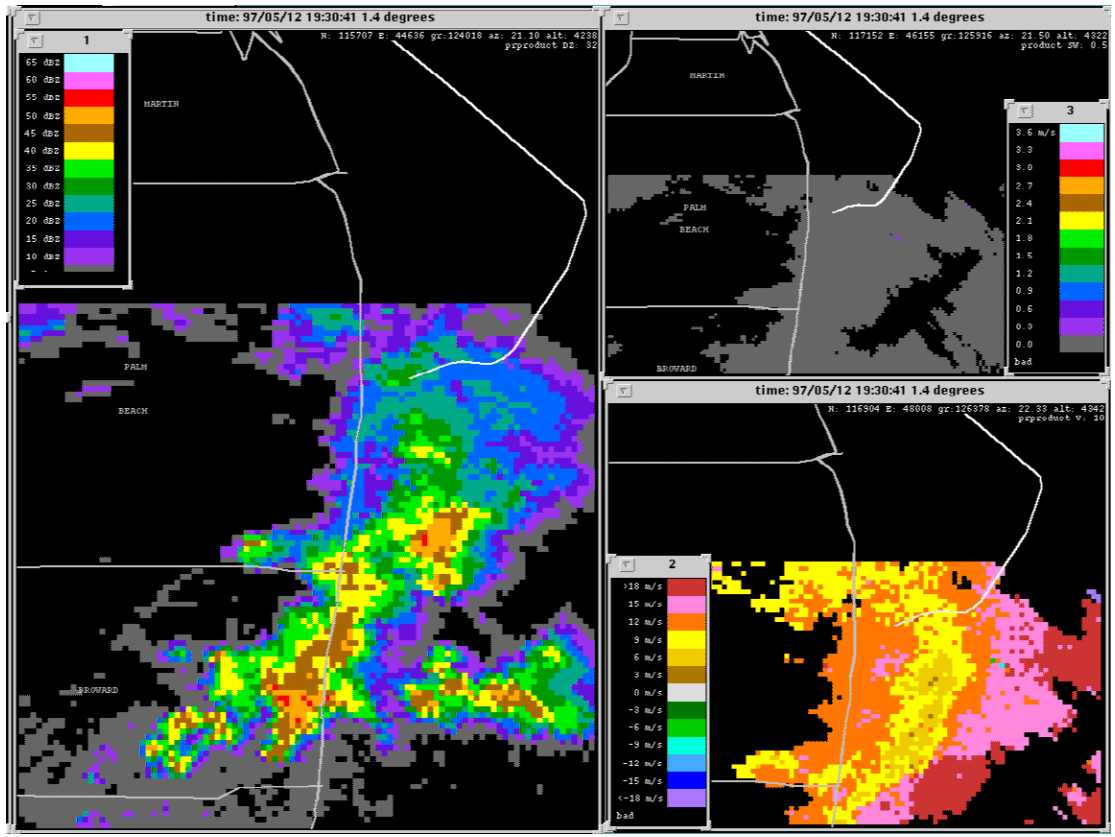
Case Study 1

- Frontal boundary
- Multi-layered clouds
- Widespread convection
- Winds at altitude: 240/35
- Only available radar-KAMX



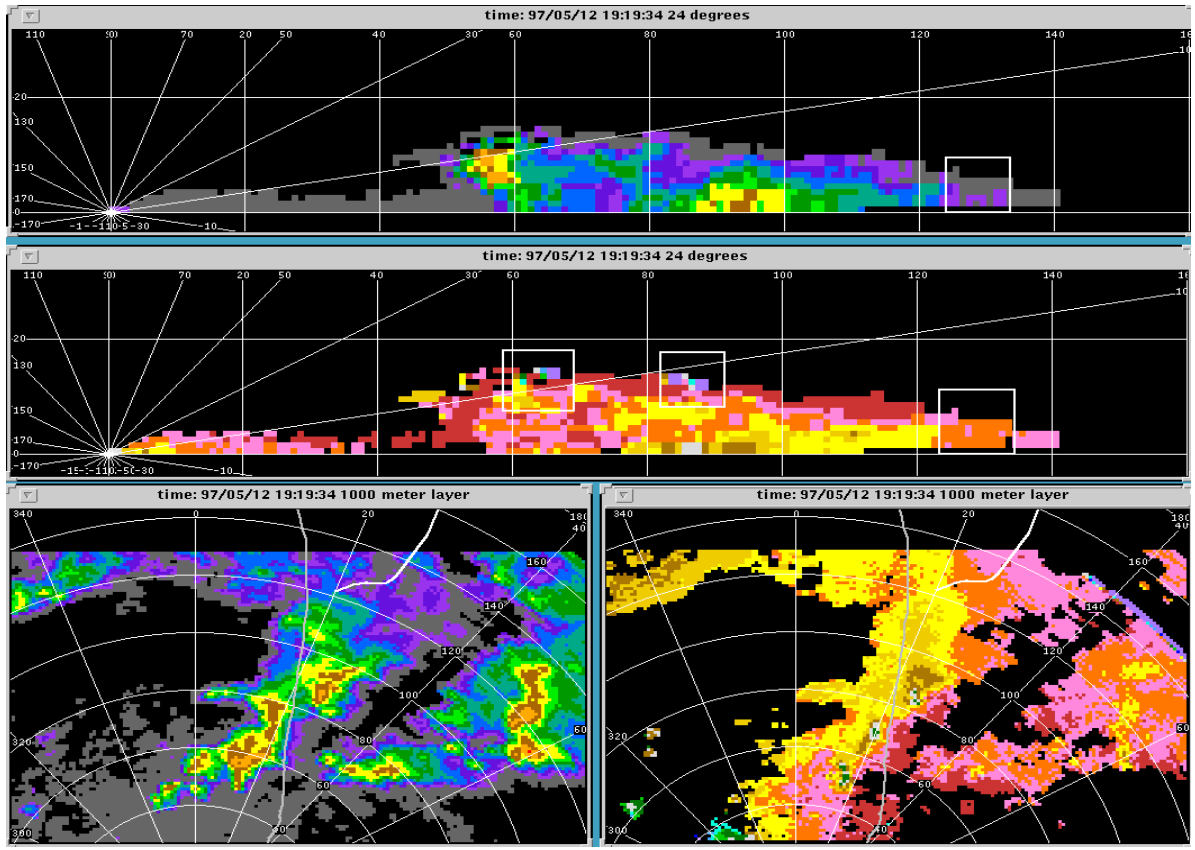
Case Study 1

- Plan view at incident time
- Nearest convection: 42 dBZ cell approximately 20 km to SSW
- Nothing indicative of severe turbulence



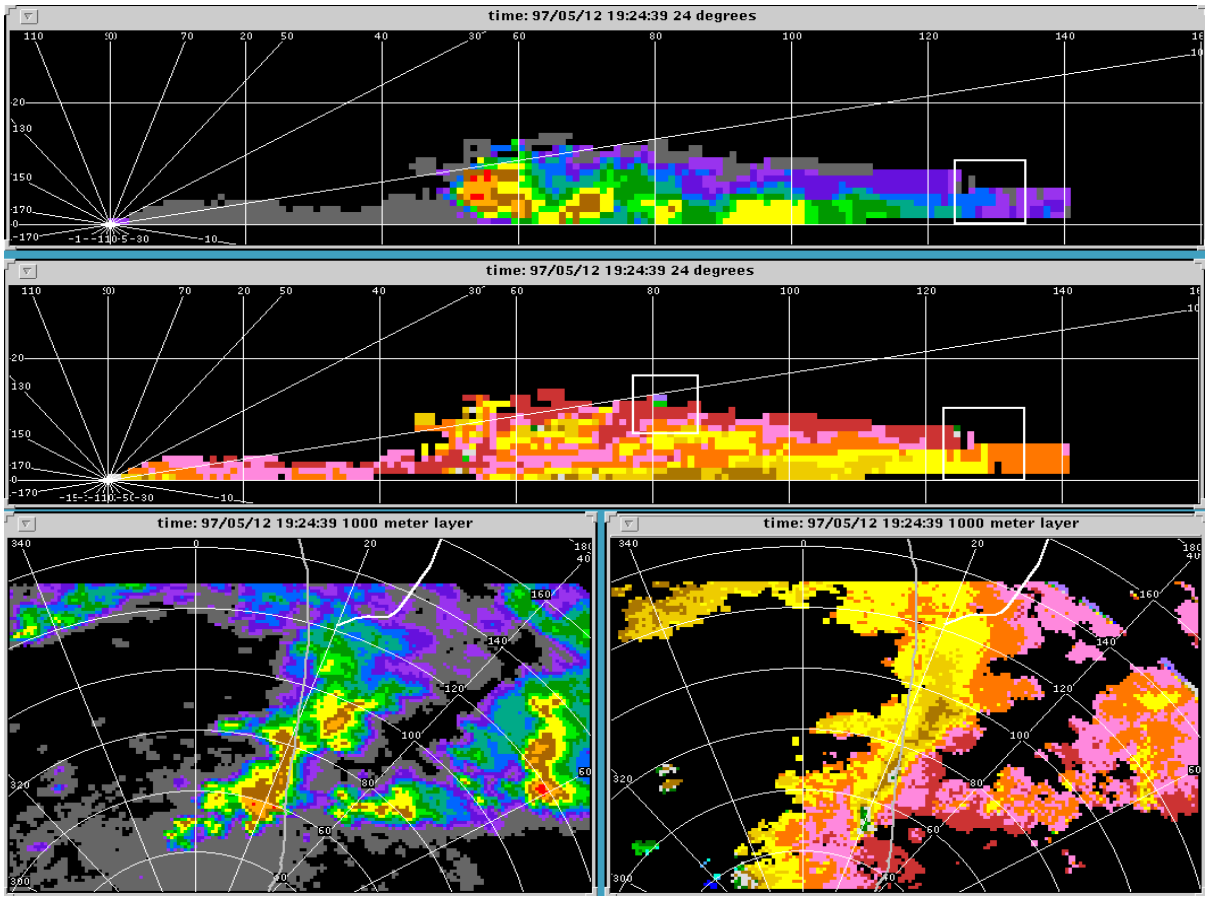
Case Study 1

- Incident along 24 degree radial at 128 nm
- Time: Approximately 10 minutes before upset
- Shear zones visible



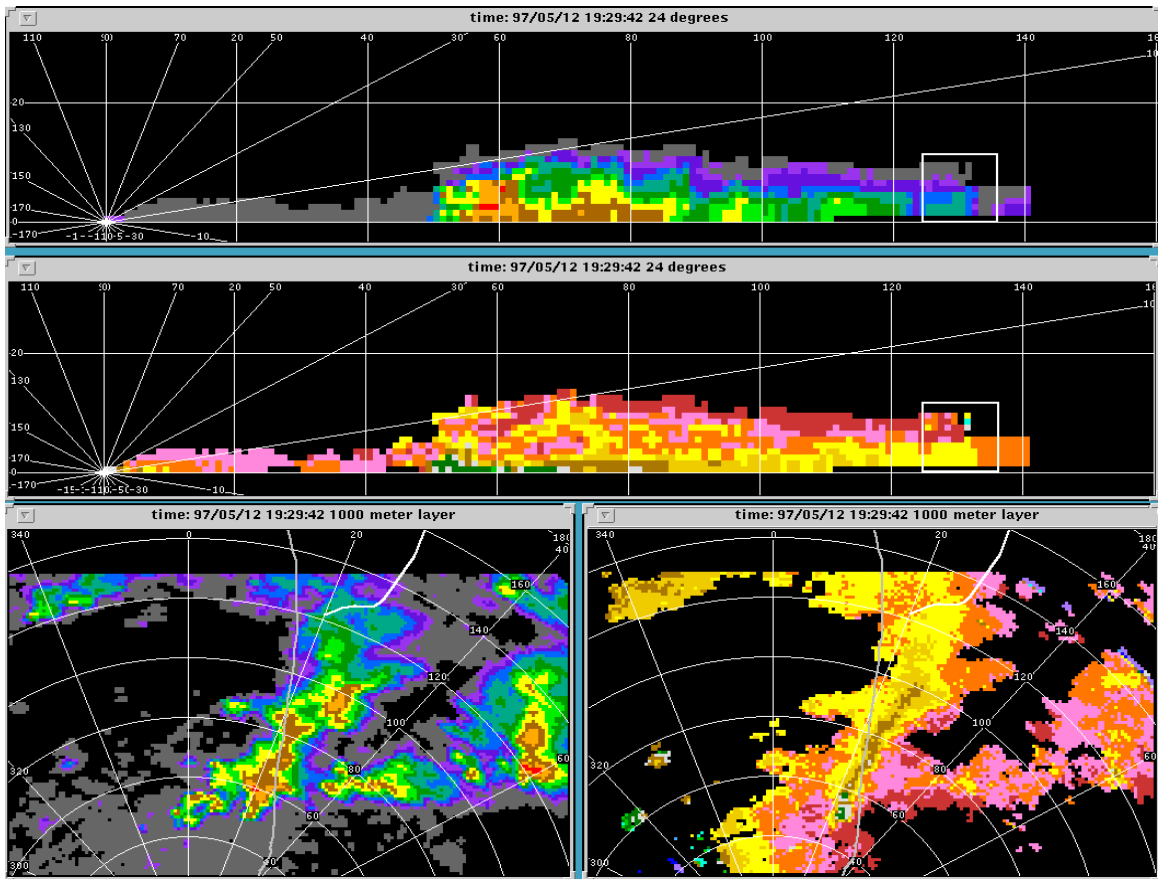
Case Study 1

- Time: Approximately 5 minutes before upset
- Shear zones remain visible



Case Study 1

- At time of upset
- 16.5 m/s couplet present approximately 3 km from aircraft

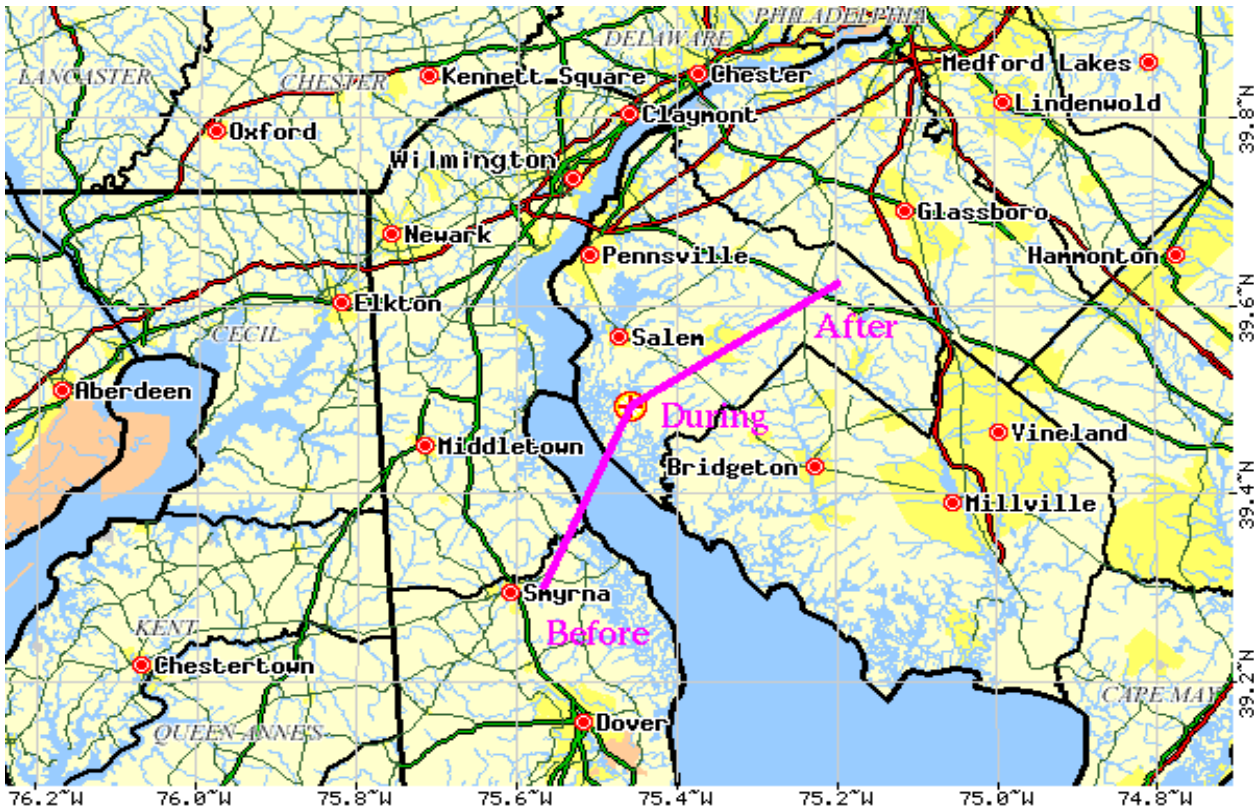


Case Study 1 Conclusions

- Aircraft was flying outside and downwind of convection
- Aircraft experienced upset indicative of severe turbulence
- Initial data revealed nothing exceptional
- Cross-sectional analysis and supporting evidence suggest a convectively induced mid-level windshear may have impacted the aircraft's flight path
- Aircrew flight control inputs were also a major factor

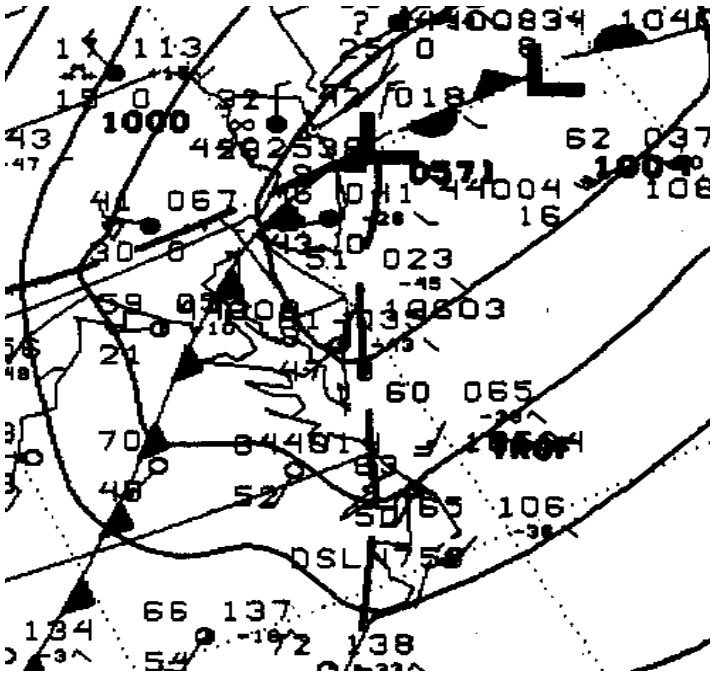
Case Study 2 (FOQA)

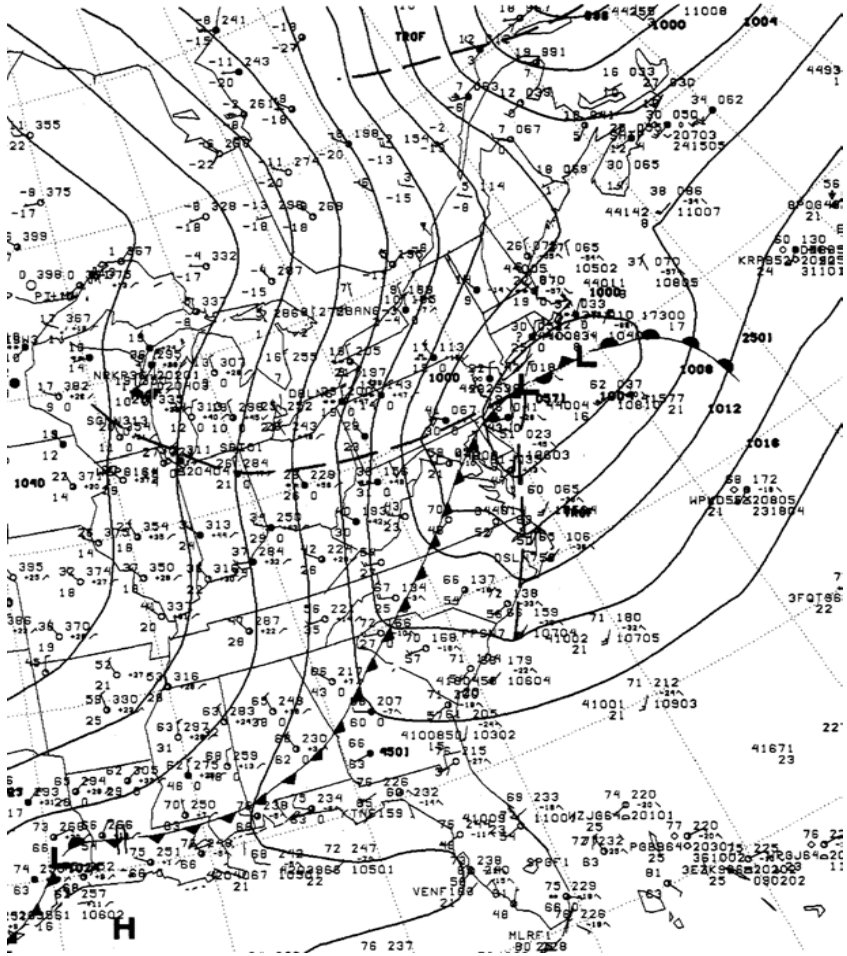
- Near Wilmington, DE
- Heading: 49.6 degrees
- Comp. airspeed: 266.0 kts
- Altitude: 7712 ft
- Auto Pilot: On
- Max G: +1.98



Case Study 2

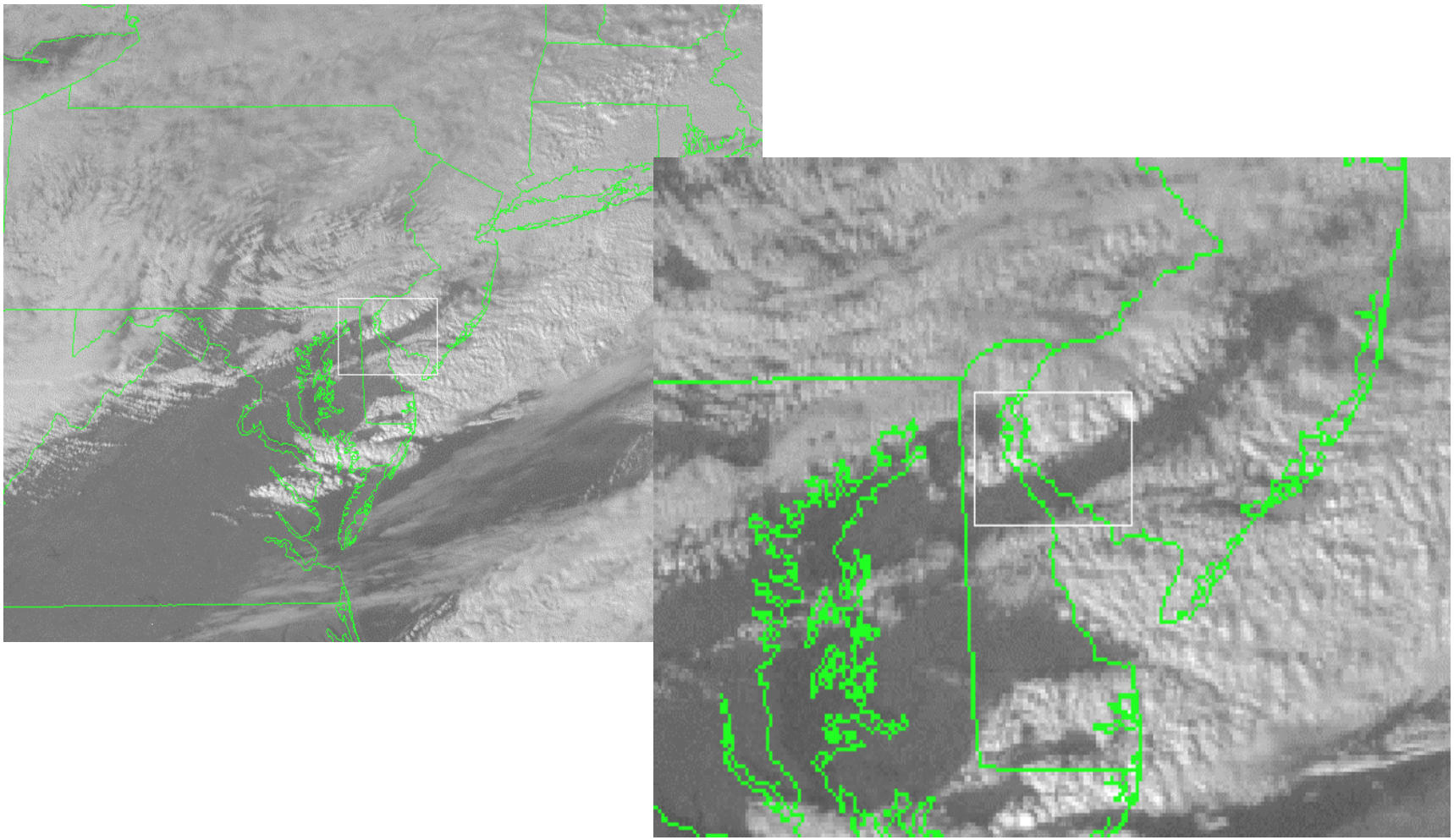
- Sfc chart at Incident - 91 min.
- Complex low off NJ coast
- Cold front/trough moving through area
- Snow and rainshowers from NE to Virginia





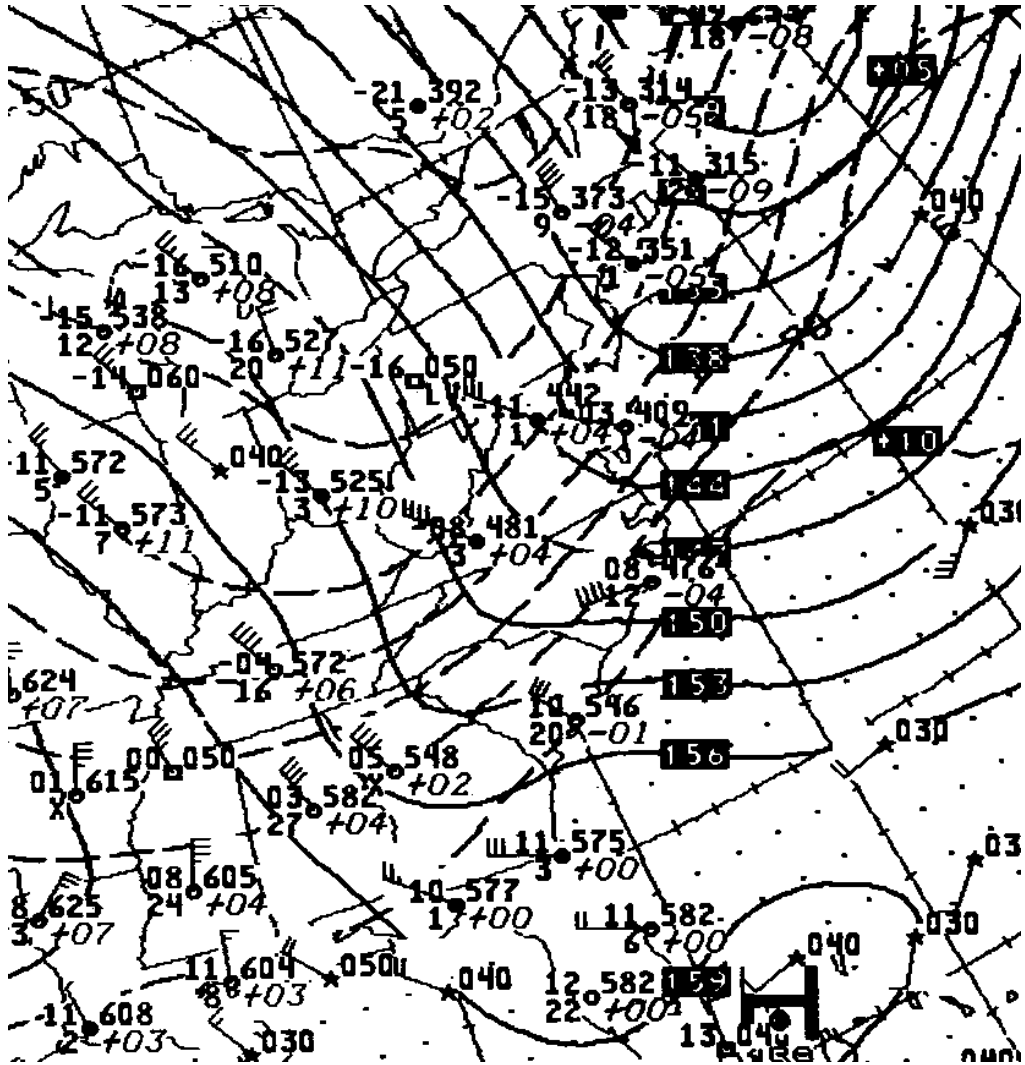
Case Study 2

- Satellite images approximately 1 minute after Incident (I)



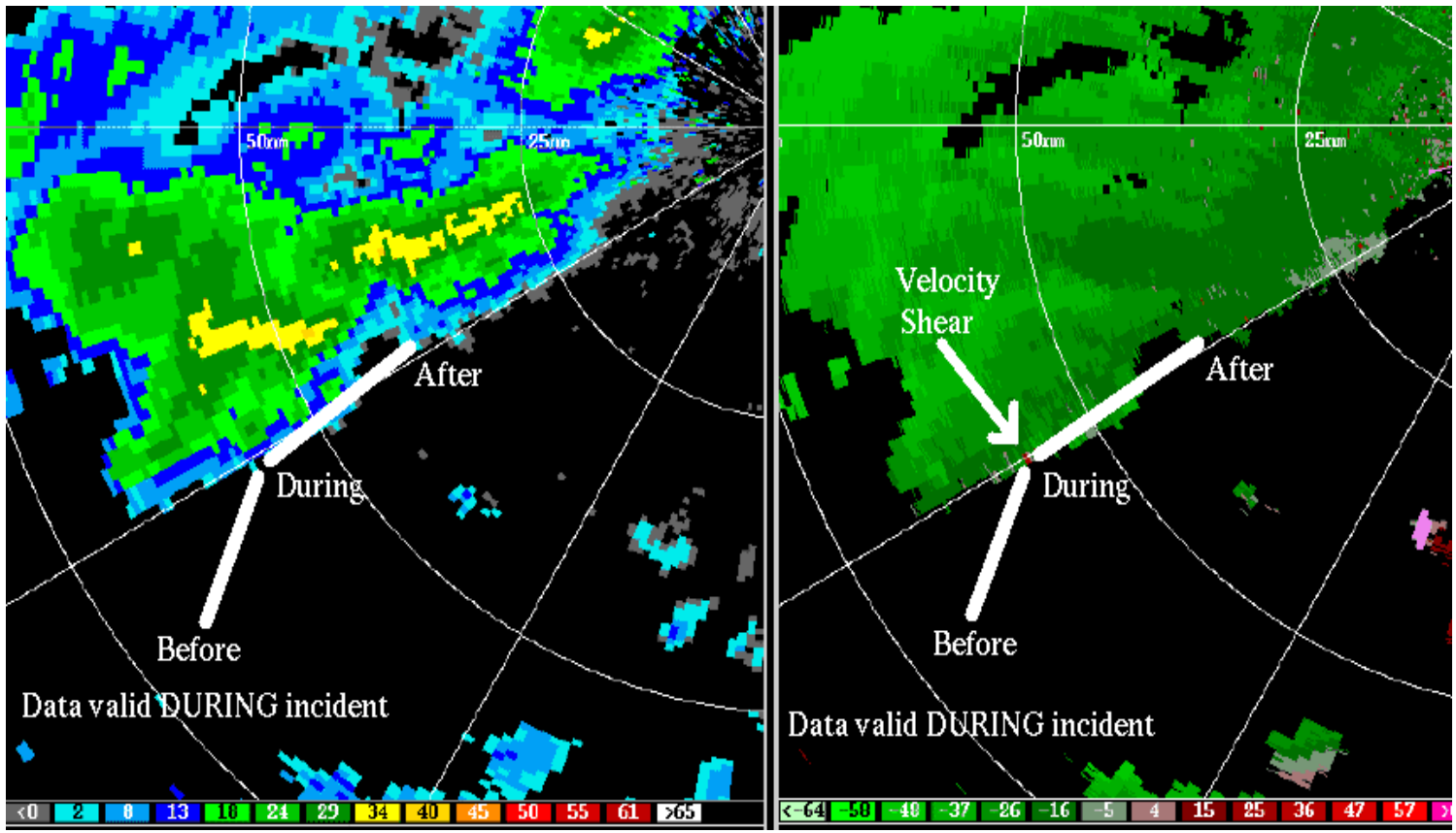
Case Study 2

- 850 mb (5000 ft) winds at I+4.5 hrs. (310/45)
- Trough in area
- Strong cold air advection



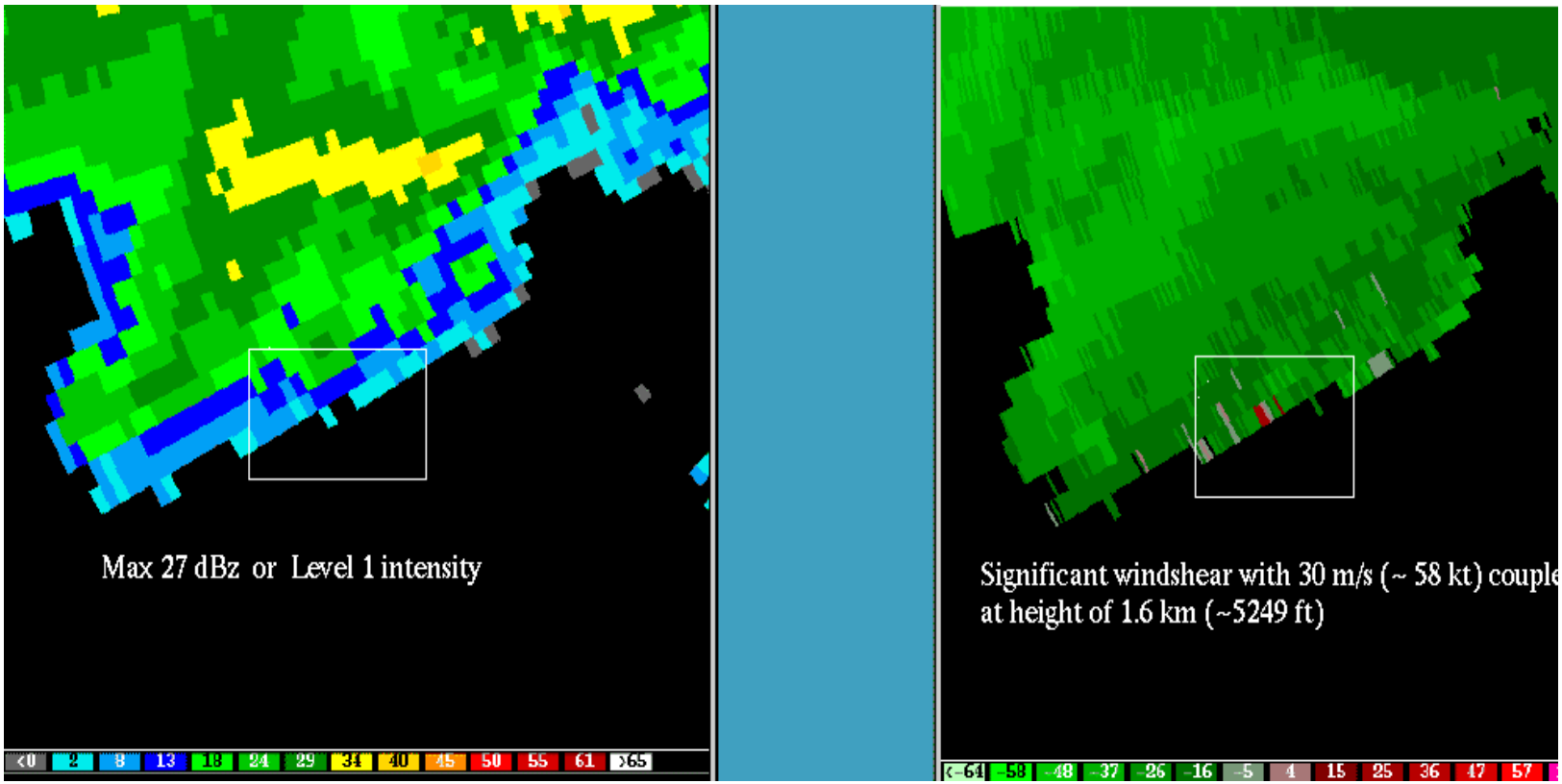
Case Study 2

- NEXRAD reflectivity (left) and velocity (right) during Incident



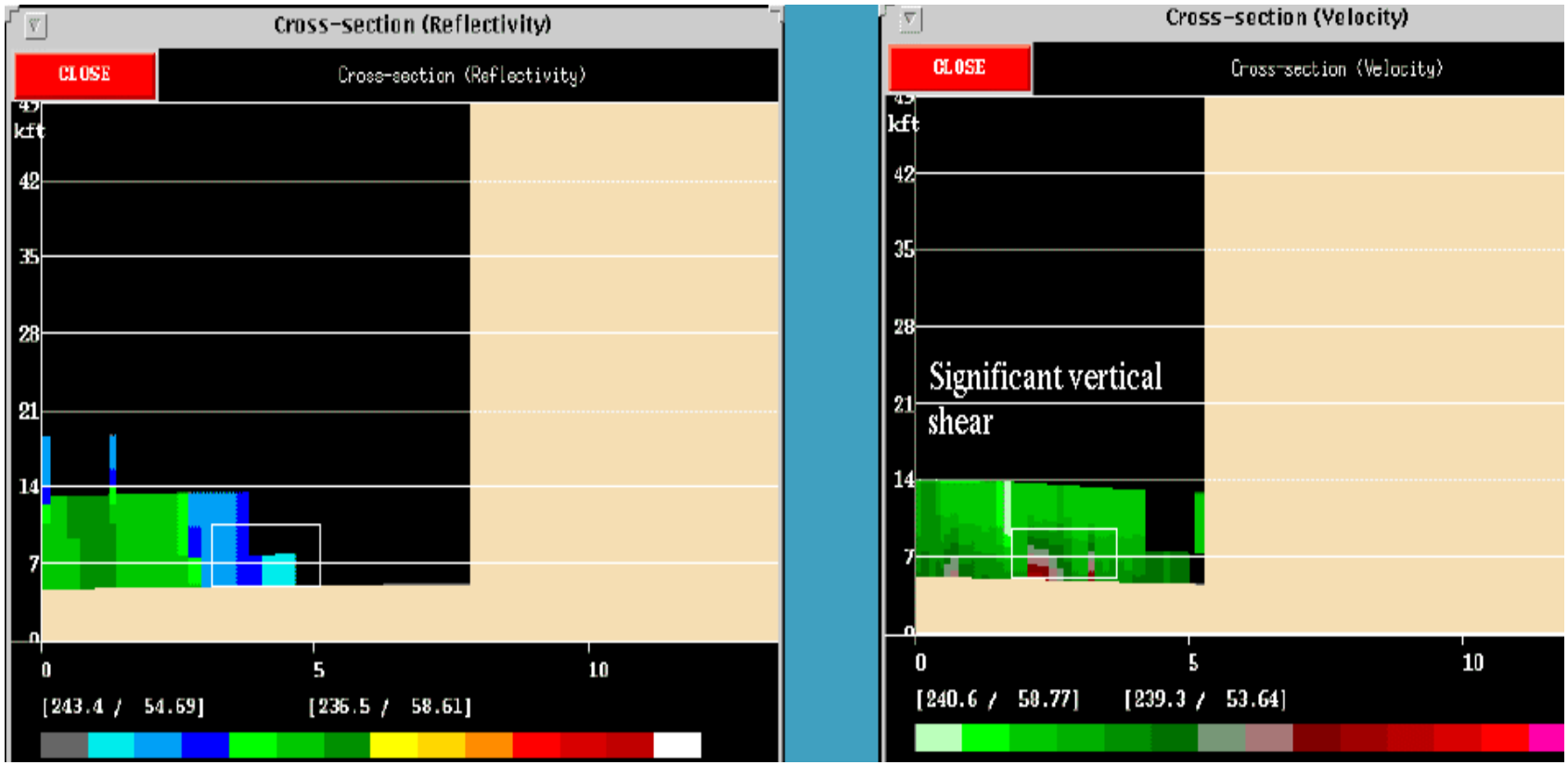
Case Study 2

- Enlarged version of previous images during Incident



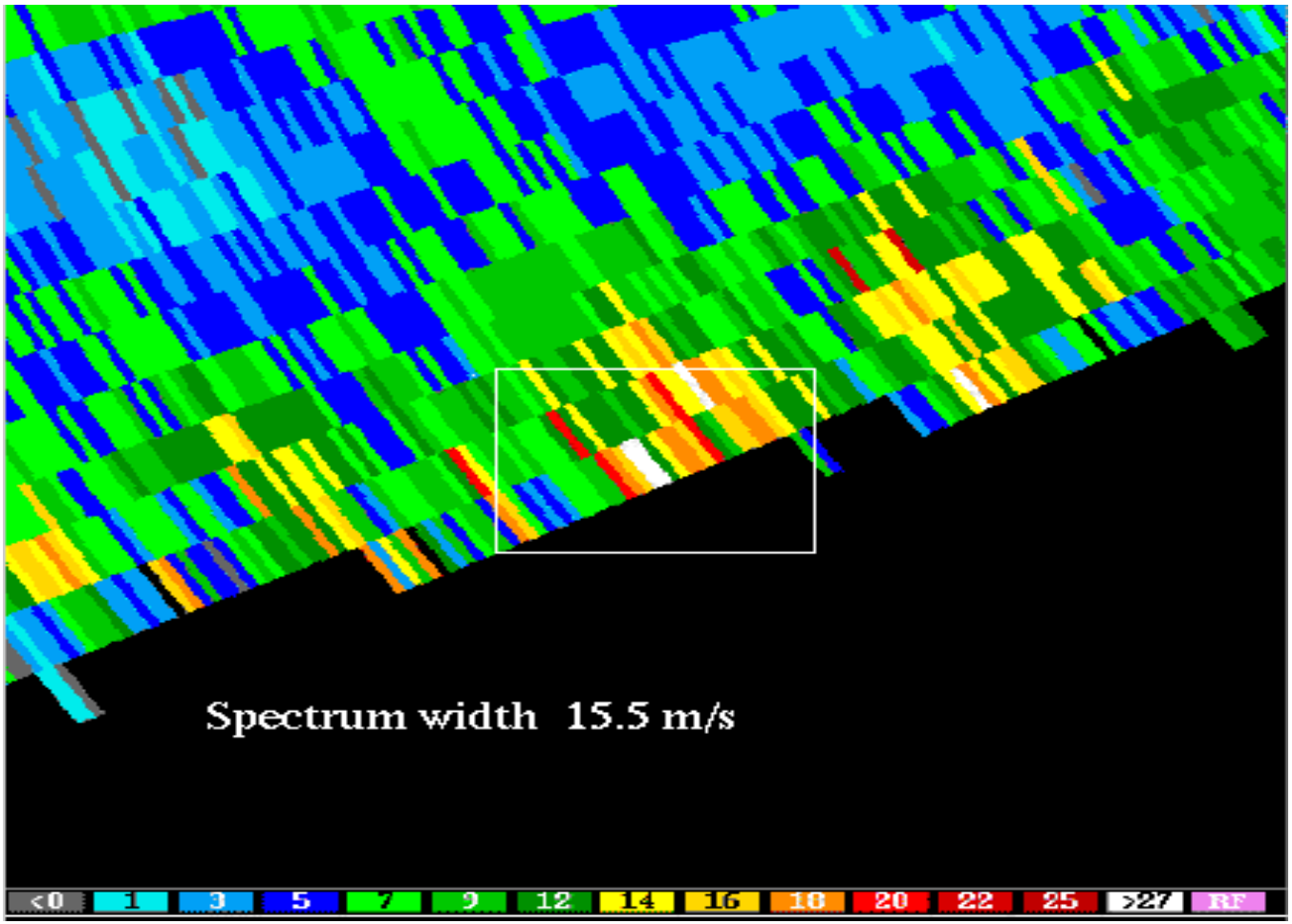
Case Study 2

- Vertical cross section at l - 2 min.
- Significant velocity shear



Case Study 2

- **Spectrum width value of 15.5 m/s**

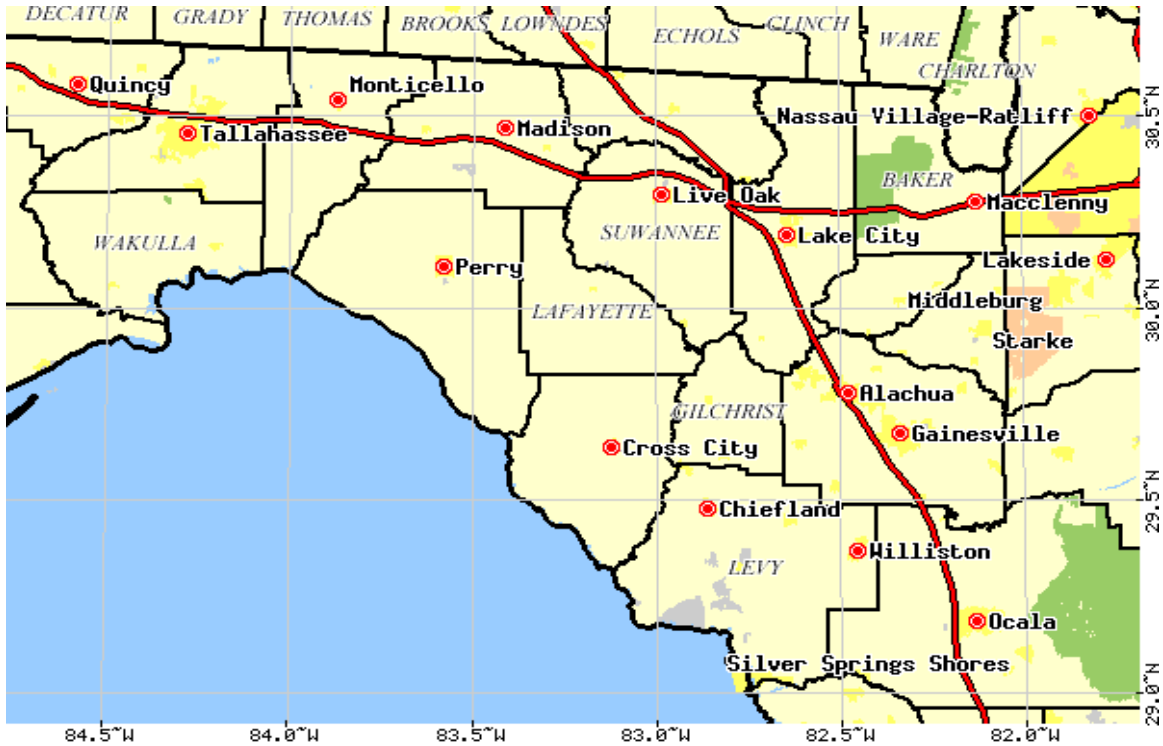


Case Study 2 Conclusions

- Aircraft entered line of convection induced by front/trough
- Reflectivity values in area of 27 - 39 dBZ
- Small but significant velocity shear of 30 m/s present
- Spectrum width indications of severe turbulence
- Upset likely caused by penetration of boundary between line of convection (rising air) and dry slot (sinking air)

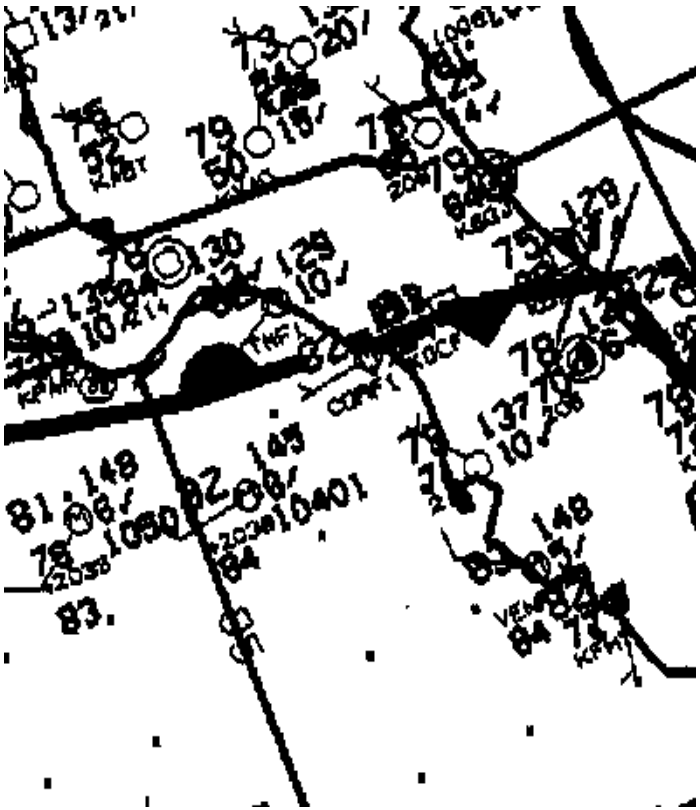
Case Study 3 (NTSB)

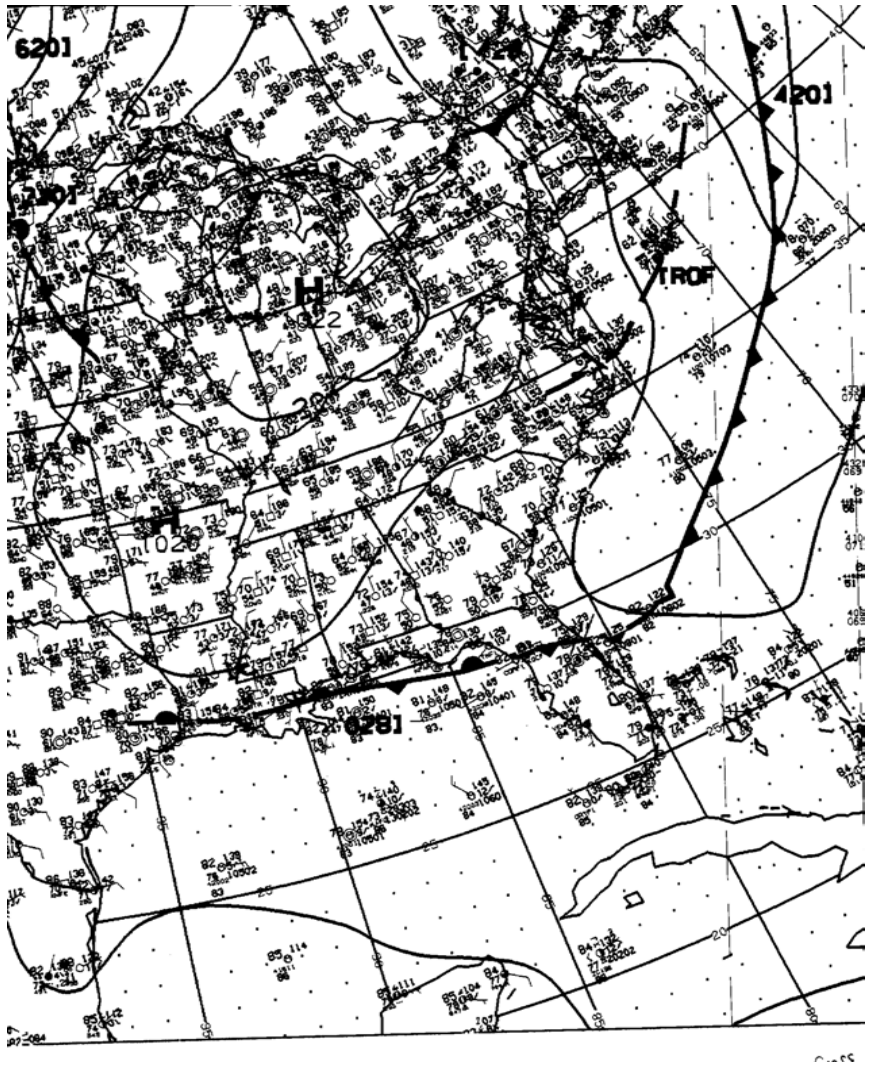
- Near Cross City, FL
- IMC at cruise altitude of FL330
- One second of moderate turbulence
- Max G: +1.75, -0.28
- One FA seriously injured, two FA and one pax - minor injuries



Case Study 3

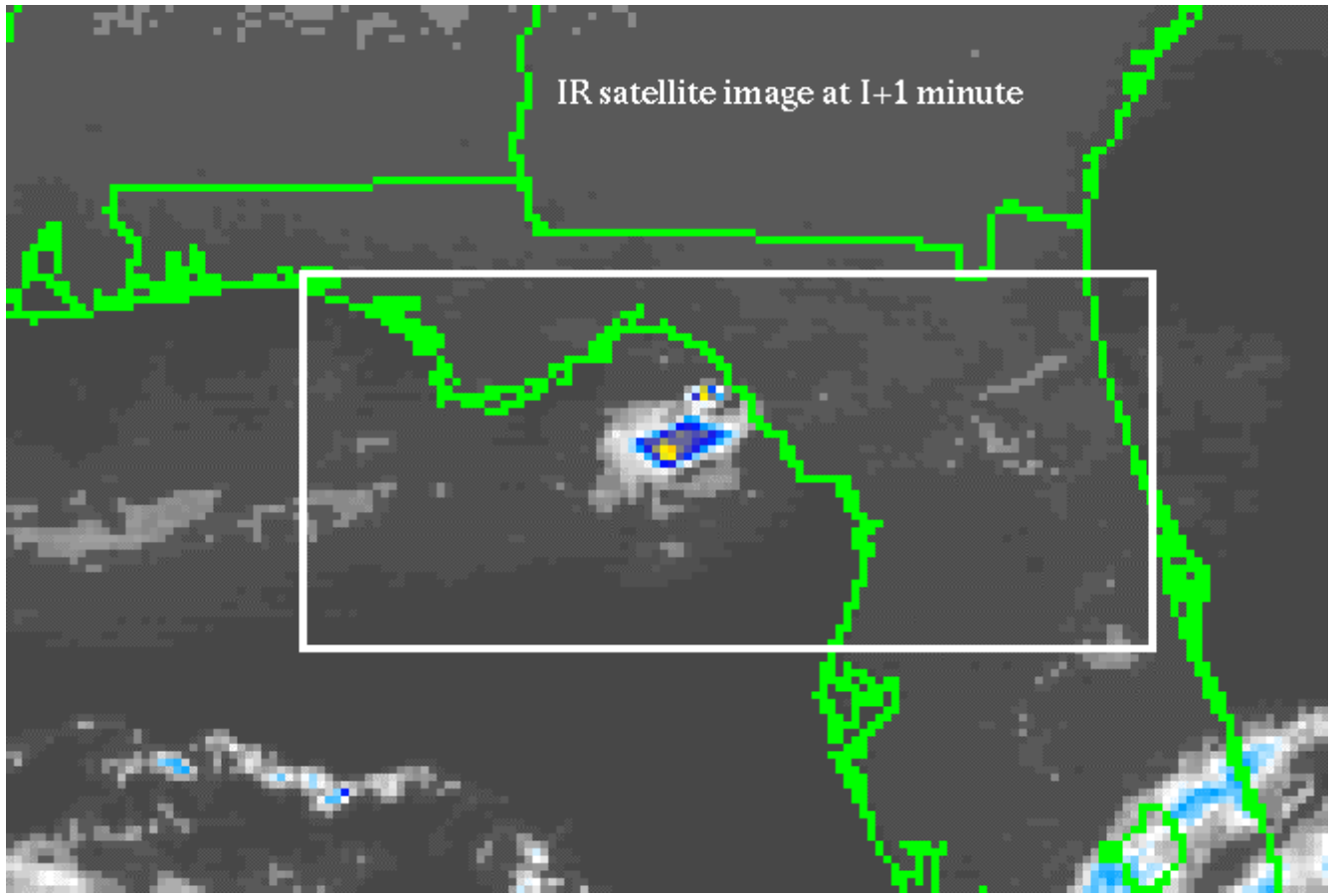
- Sfc chart at I - 44 minutes
- Stationary front through area
- High temps/dew points





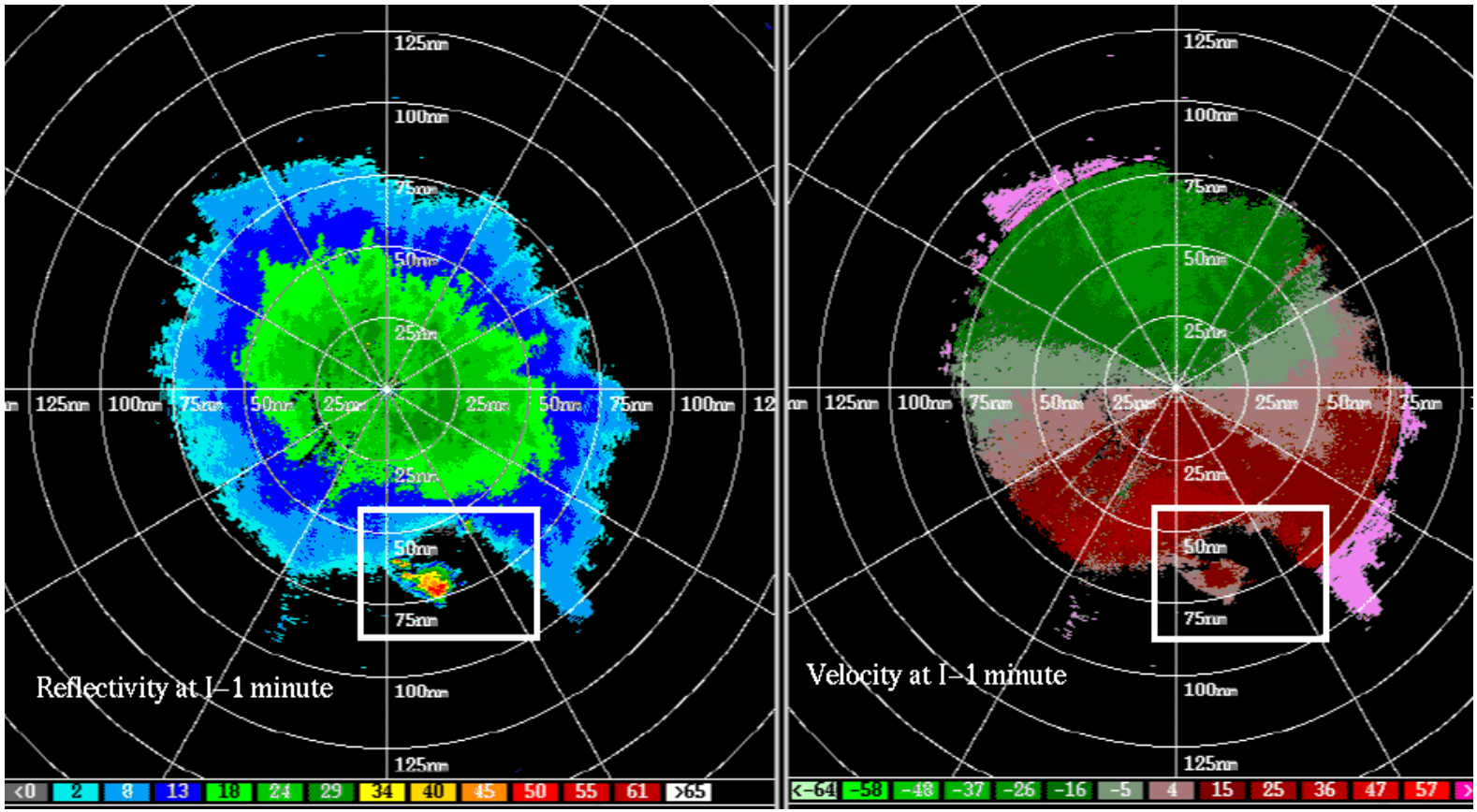
Case Study 3

- IR satellite image at I + 1min



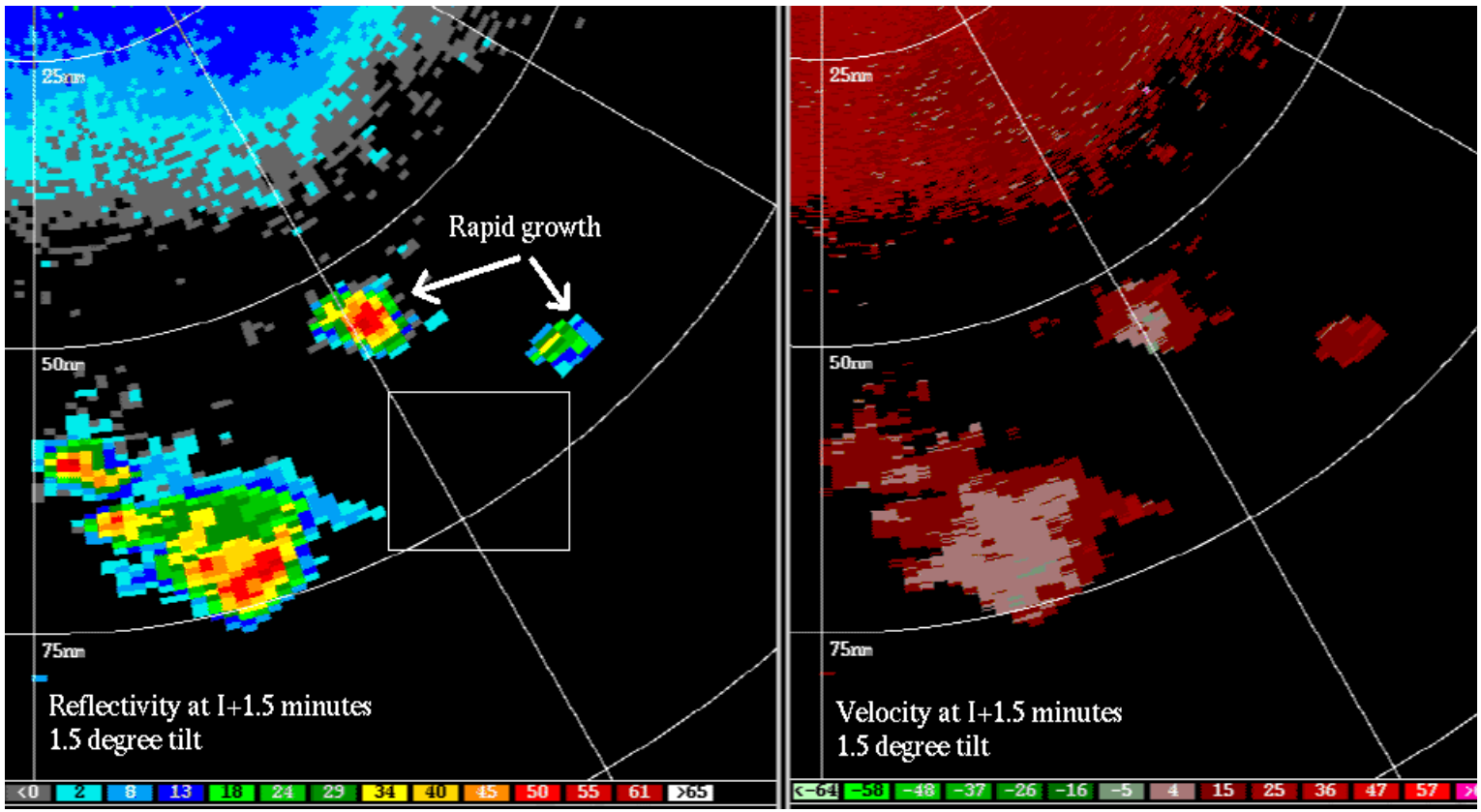
Case Study 3

- Level 5 thunderstorm just west of aircraft 1 min <u>before</u> upset
- Rapid motion to southeast



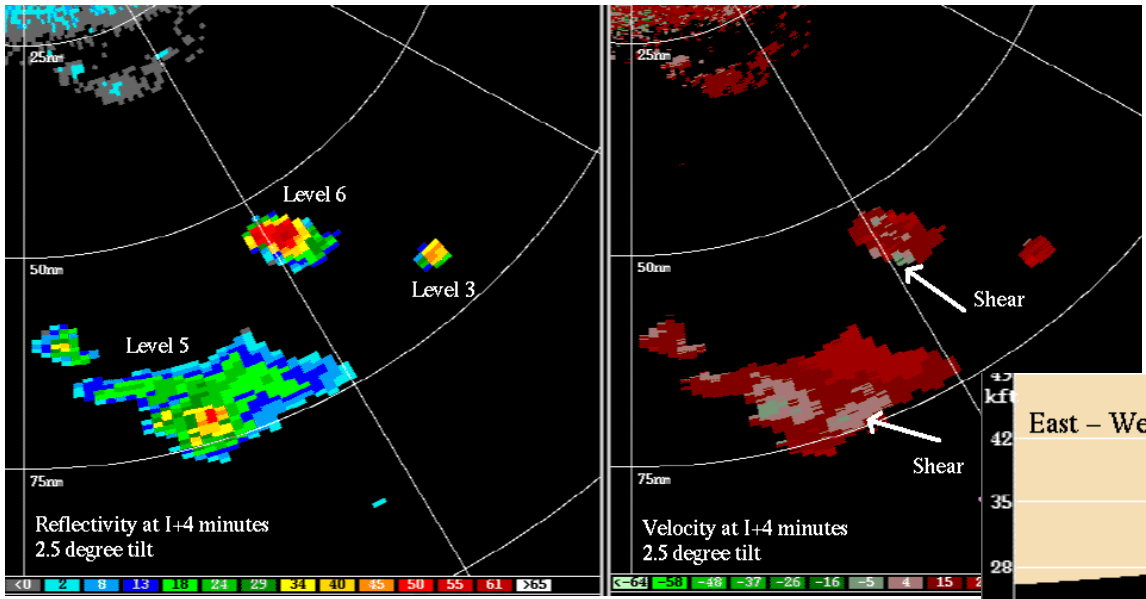
Case Study 3

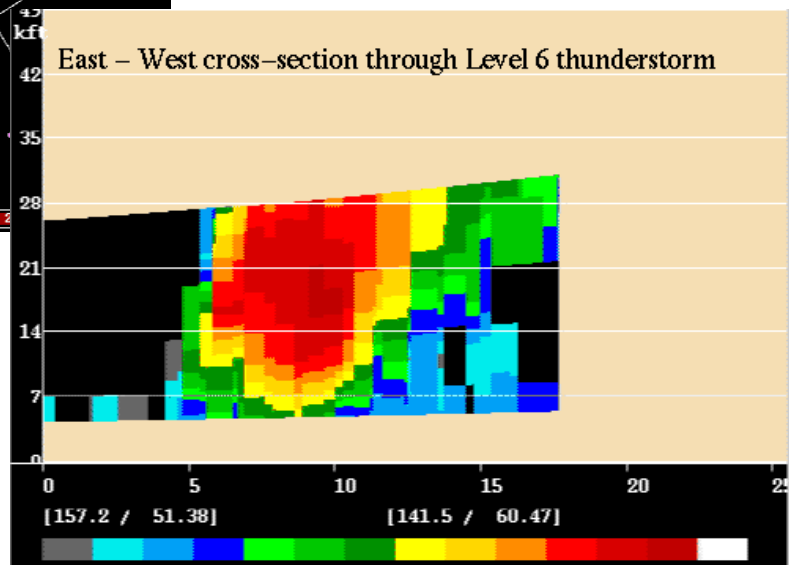
- New thunderstorms at 1.5 minutes <u>after</u> upset to N and NE
- Confirmed by pilot



Case Study 3

- Upper level shear noted in both major storms at I + 4 min.
- Max shear of 16.5 knots



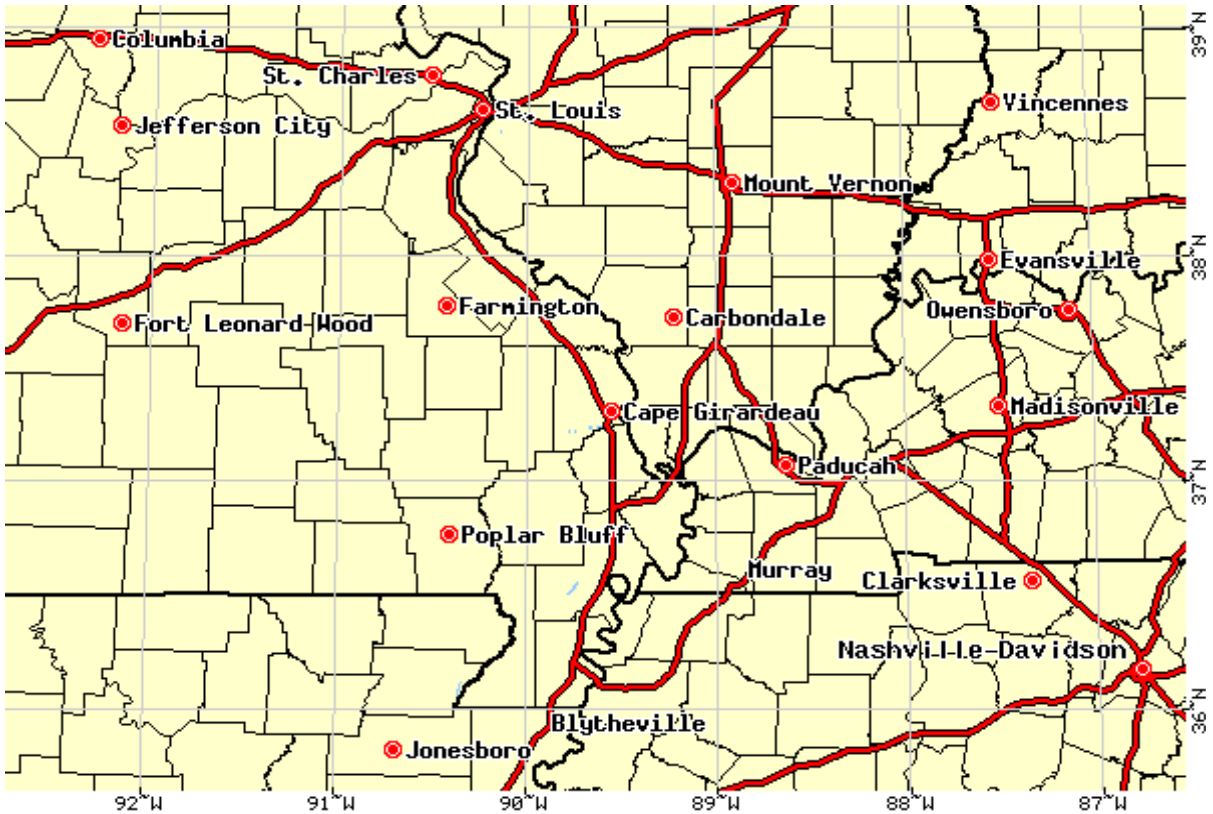


Case Study 3 Conclusions

- Original level 5 thunderstorm produced outflow
- Explosive secondary growth, especially at mid-levels
- Level 6 thunderstorm in area likely produced upset

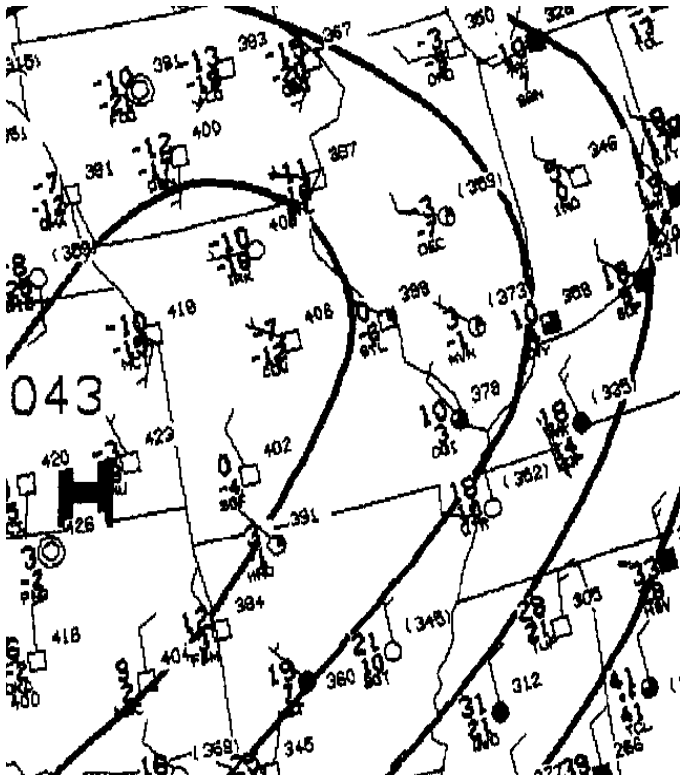
Case Study 4 (NTSB)

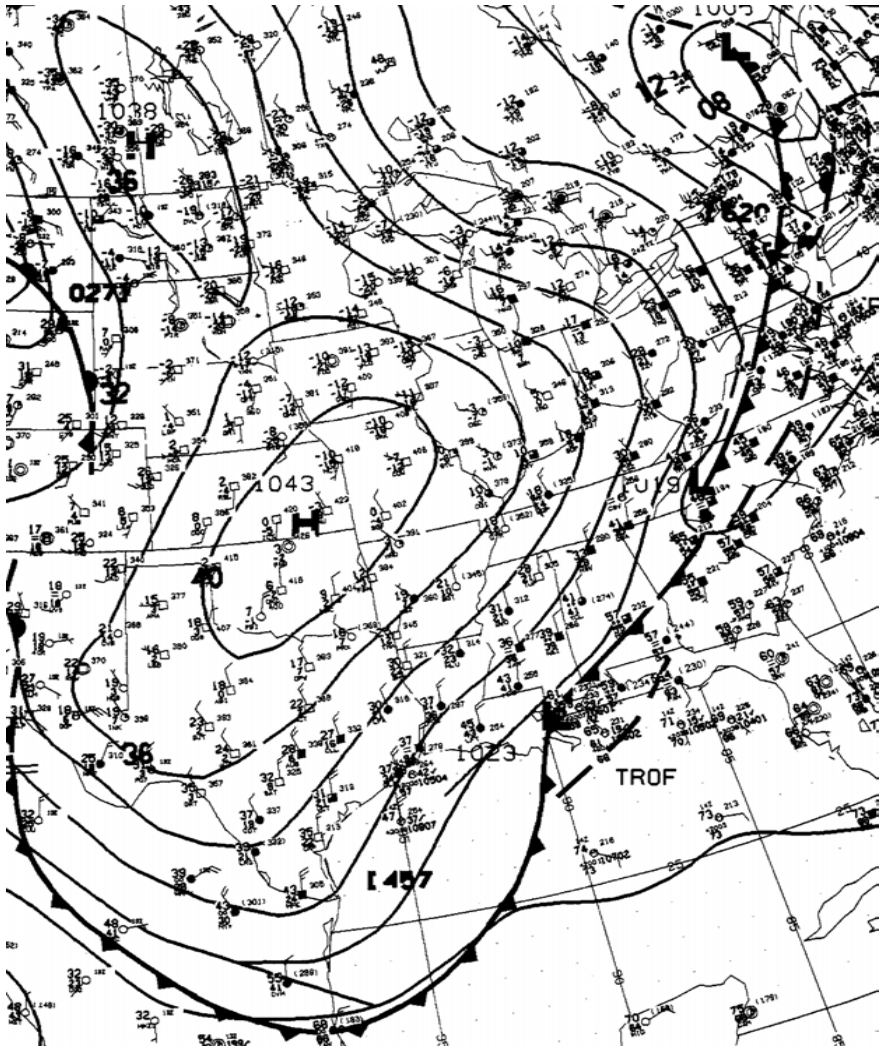
- Near Cape Girardeau, MO
- Initial descent from FL230
- "Intense" turbulence for 30 sec
- Max G: +2.5, -0.79
- Two FA hurt, one seriously



Case Study 4

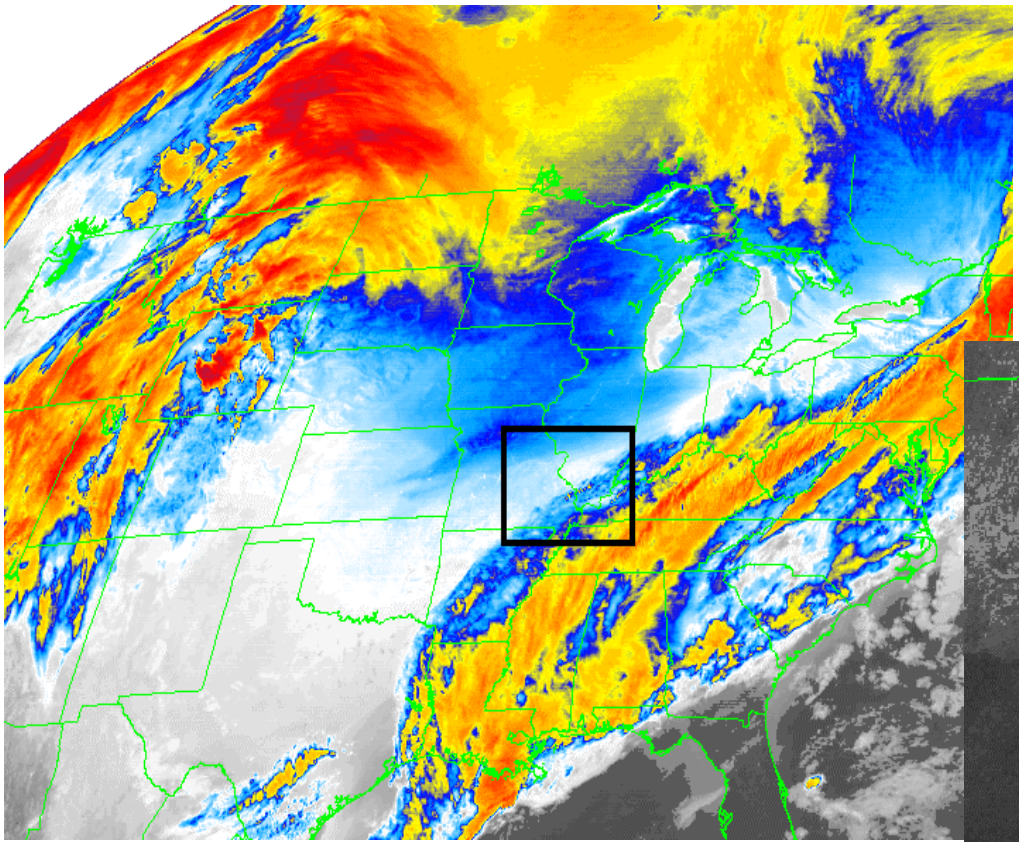
- Sfc chart at I + 10 minutes
- Strong surface high over KS/MO
- Fair weather in area

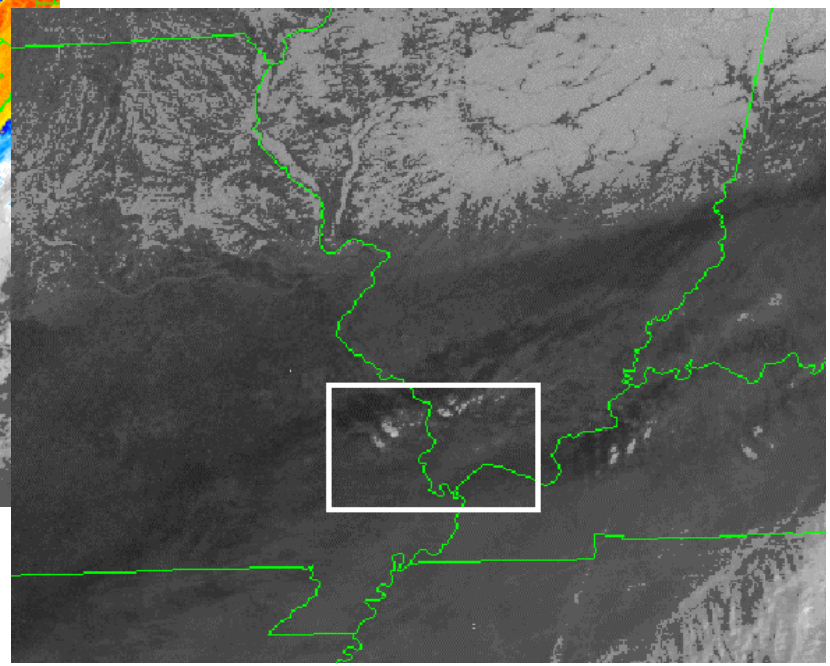




Case Study 4

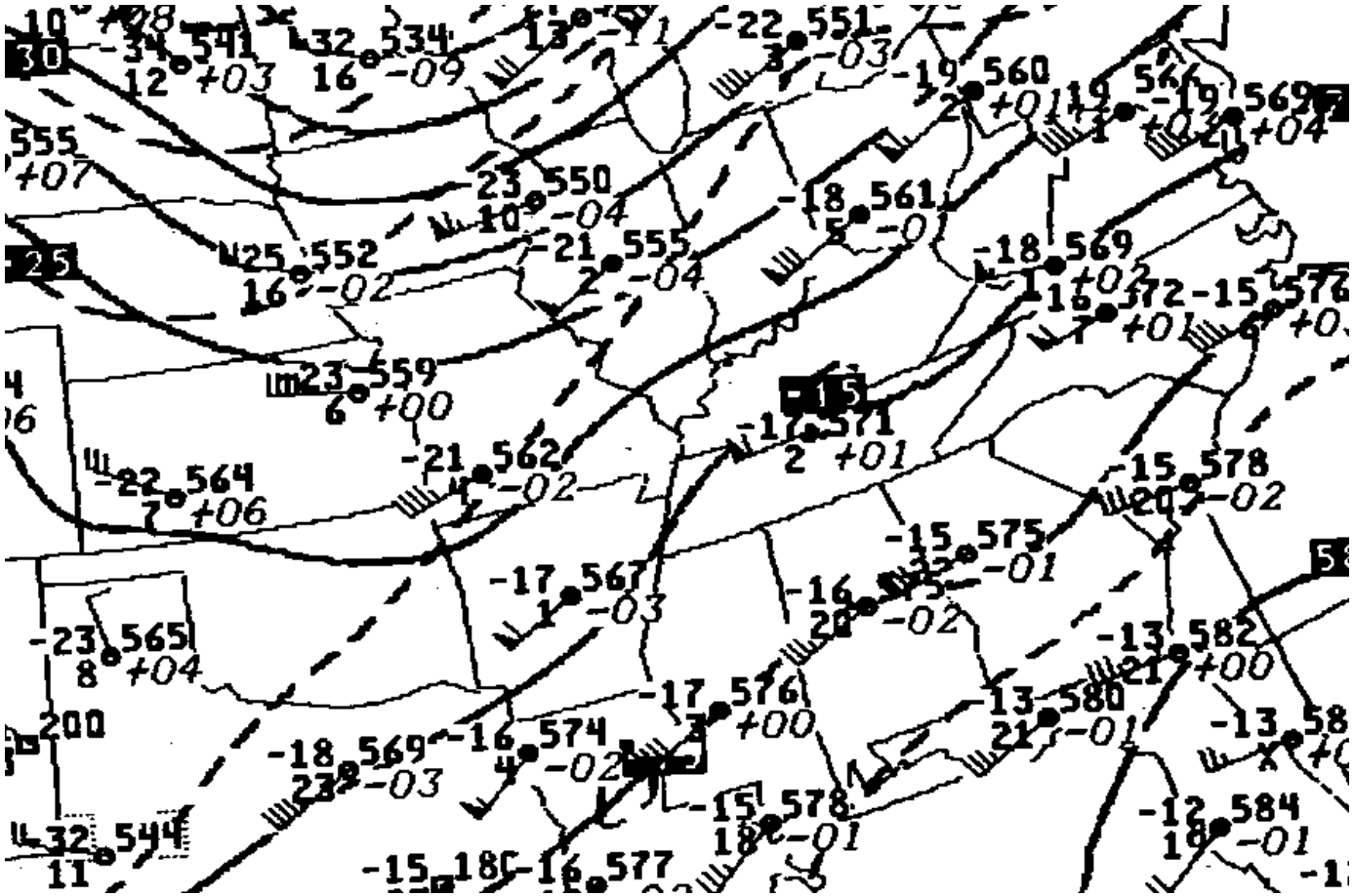
- Satellite images at I - 5 minutes





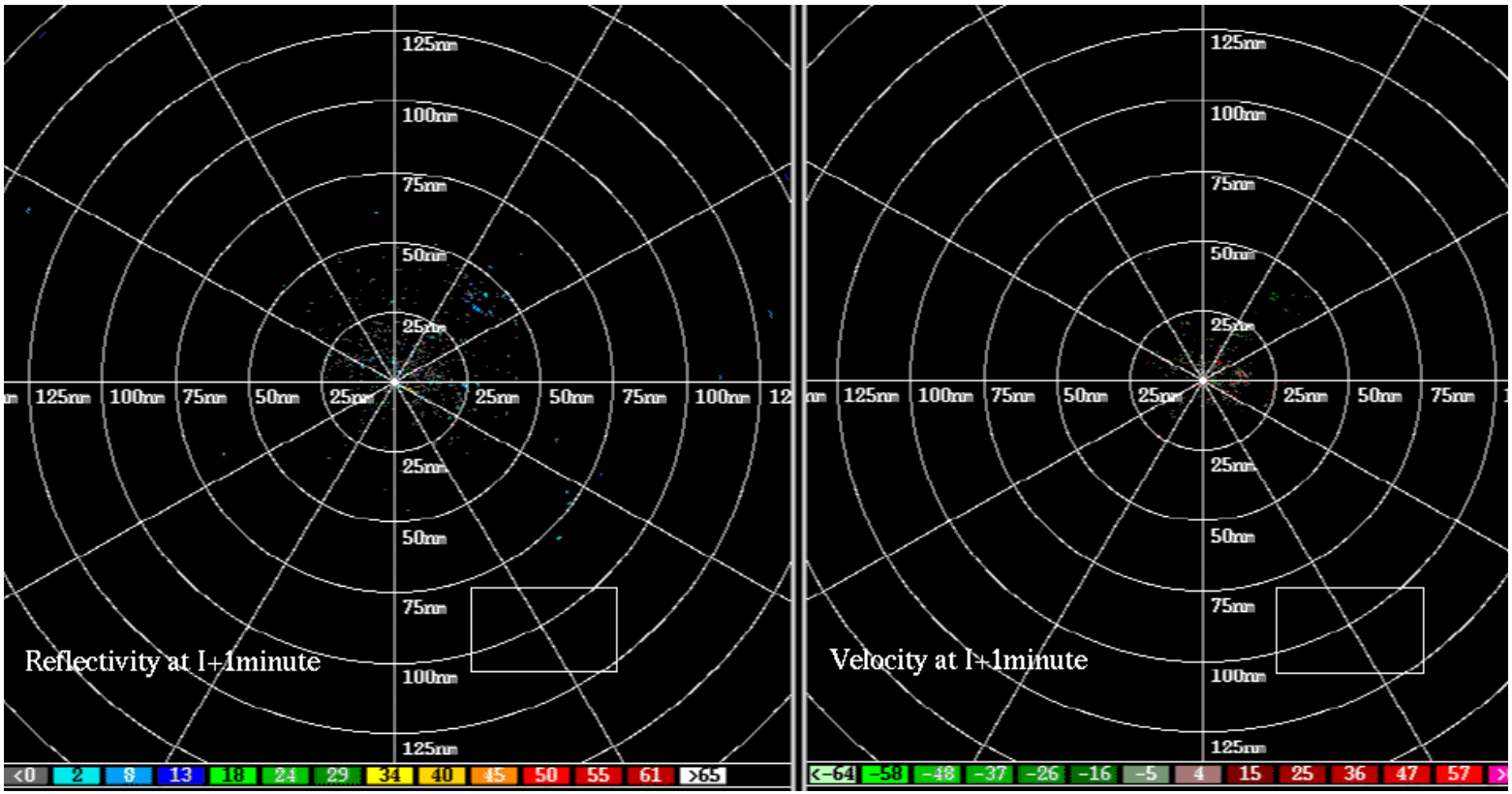
Case Study 4

- 500 mb (18,000 ft) winds at l - 4 hours (250/55 kts)



Case Study 4

- NEXRAD data 1 minute after upset
- No significant returns



Case Study 4 Conclusions

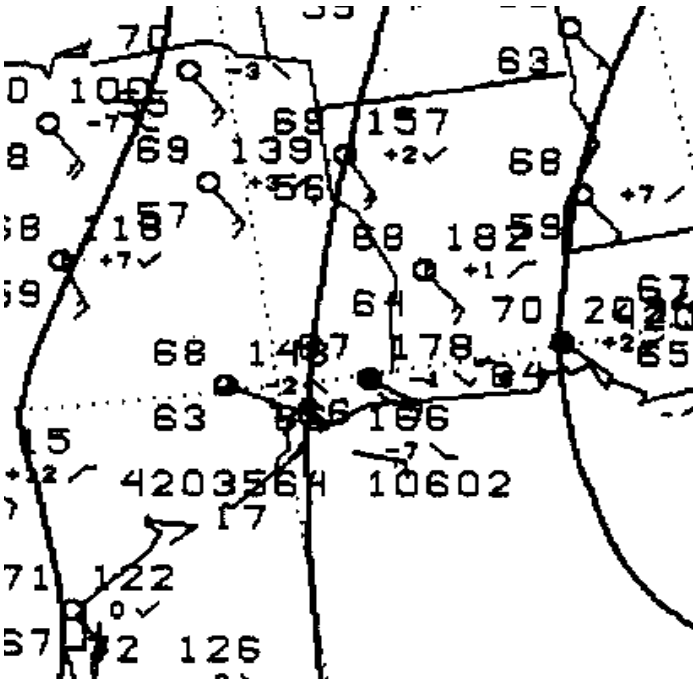
- **Aircraft likely experienced severe CAT associated with jet stream and converging winds at altitude.**

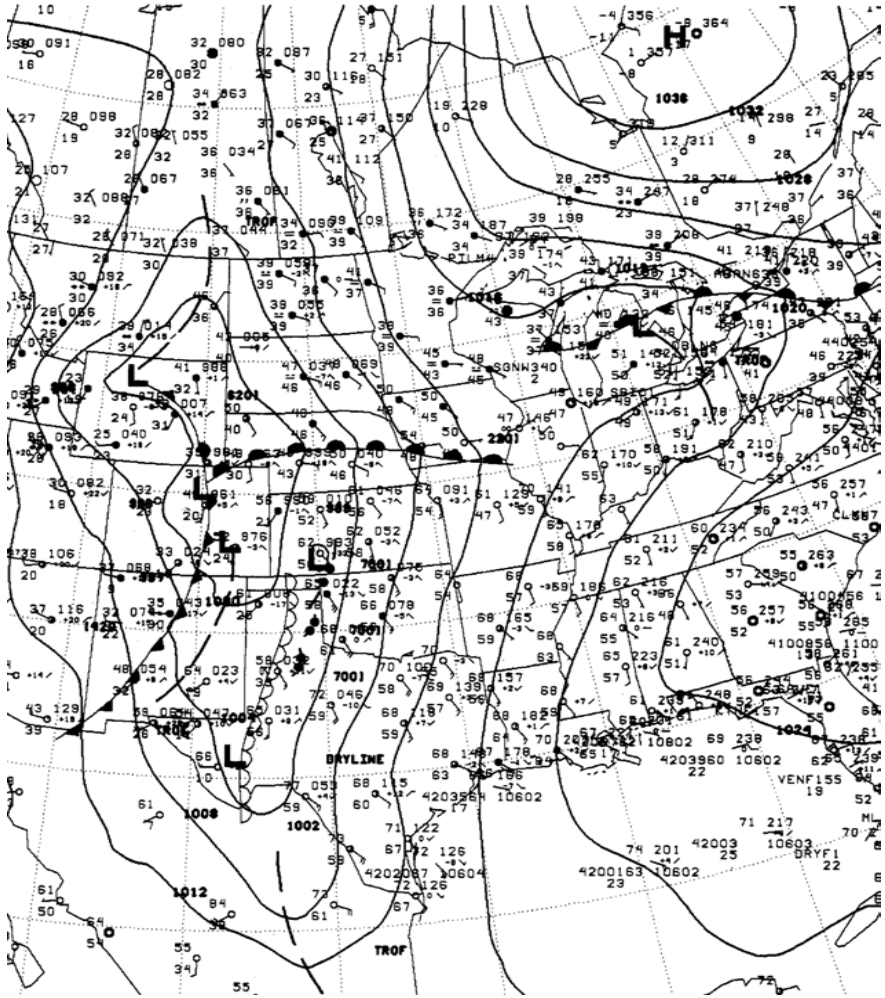
Case Study 5 (FOQA)

- Near Houston, TX
- Heading 179.8 degrees
- Comp. airspeed: 232.0 kts
- Altitude: 7648 ft
- Auto Pilot: On/Off
- Max G: +1.74

Case Study 5

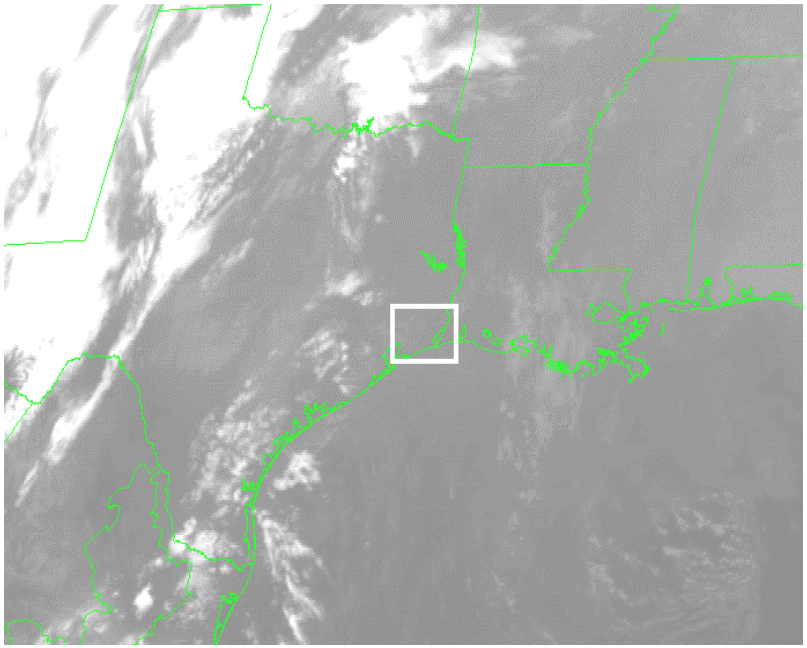
- Sfc chart at I - 1 minute
- Large high off mid-Atlantic
- Cold front exiting Rockies
- Dry line in west Texas
- No sig wx in airspace

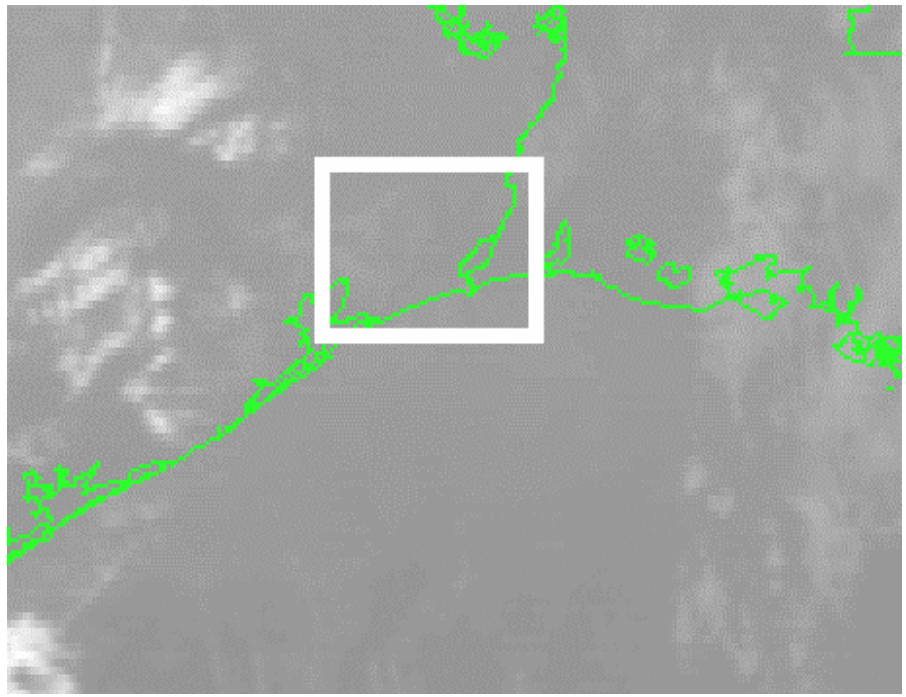




Case Study 5

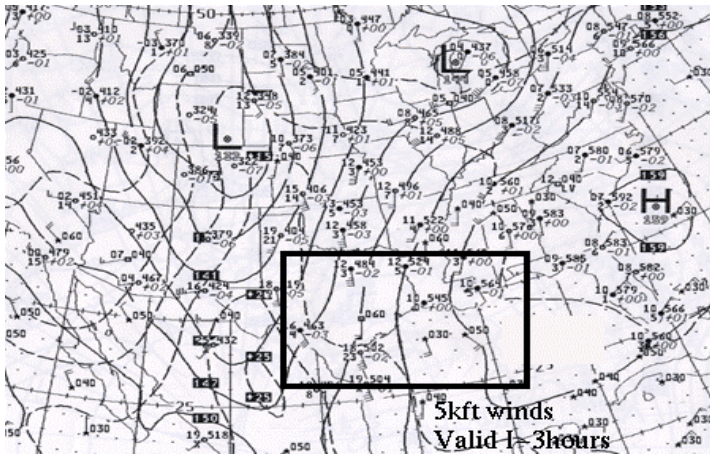
- IR satellite images taken at I - 16 minutes

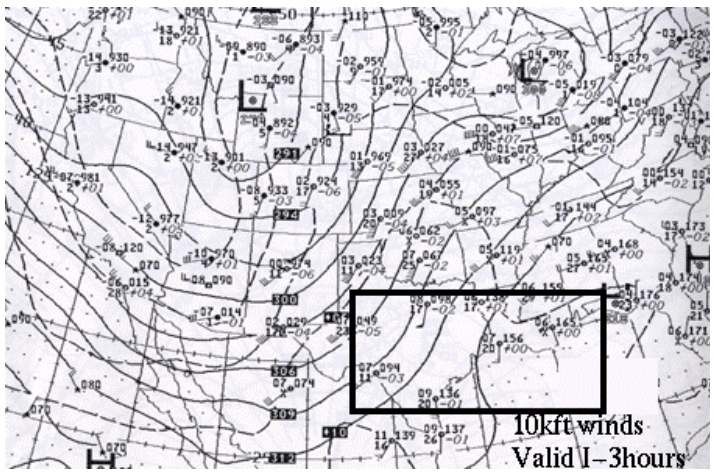


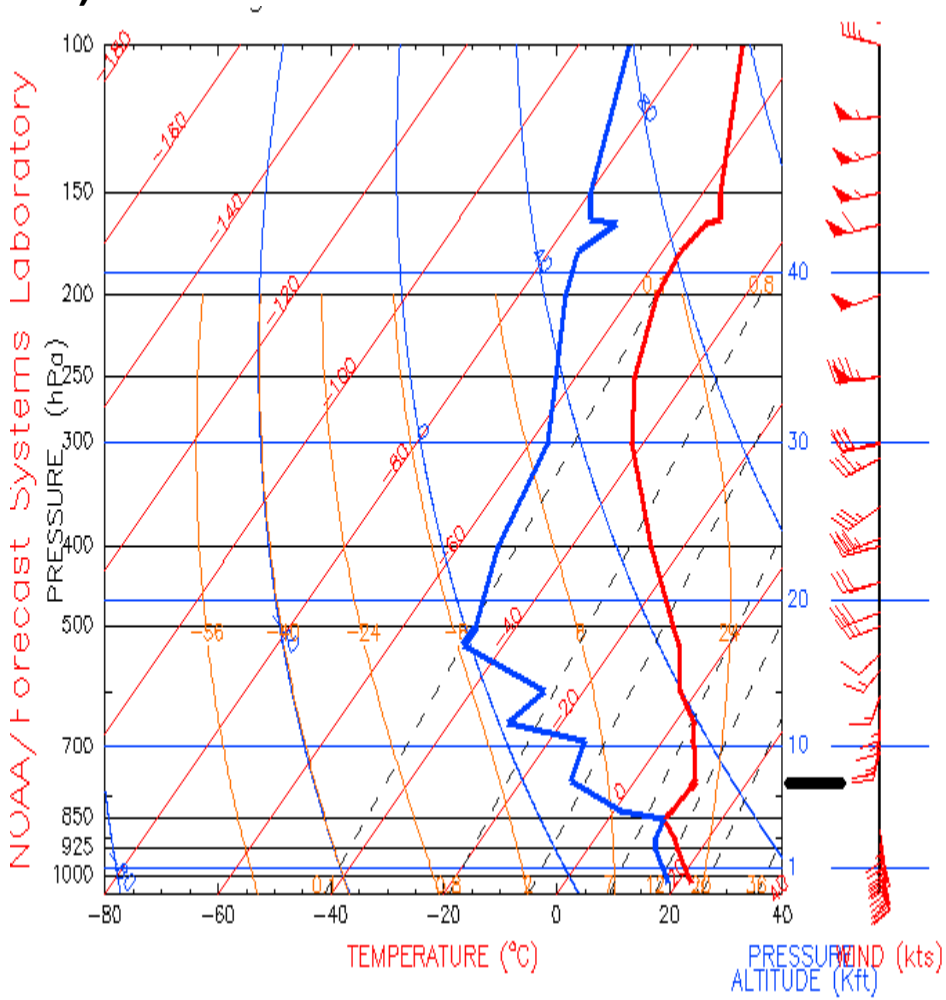


Case Study 5

- Upper air charts at 850 and 700 mb at I - 3 hours
- Vertical profile at I - 3 hours (LCH)

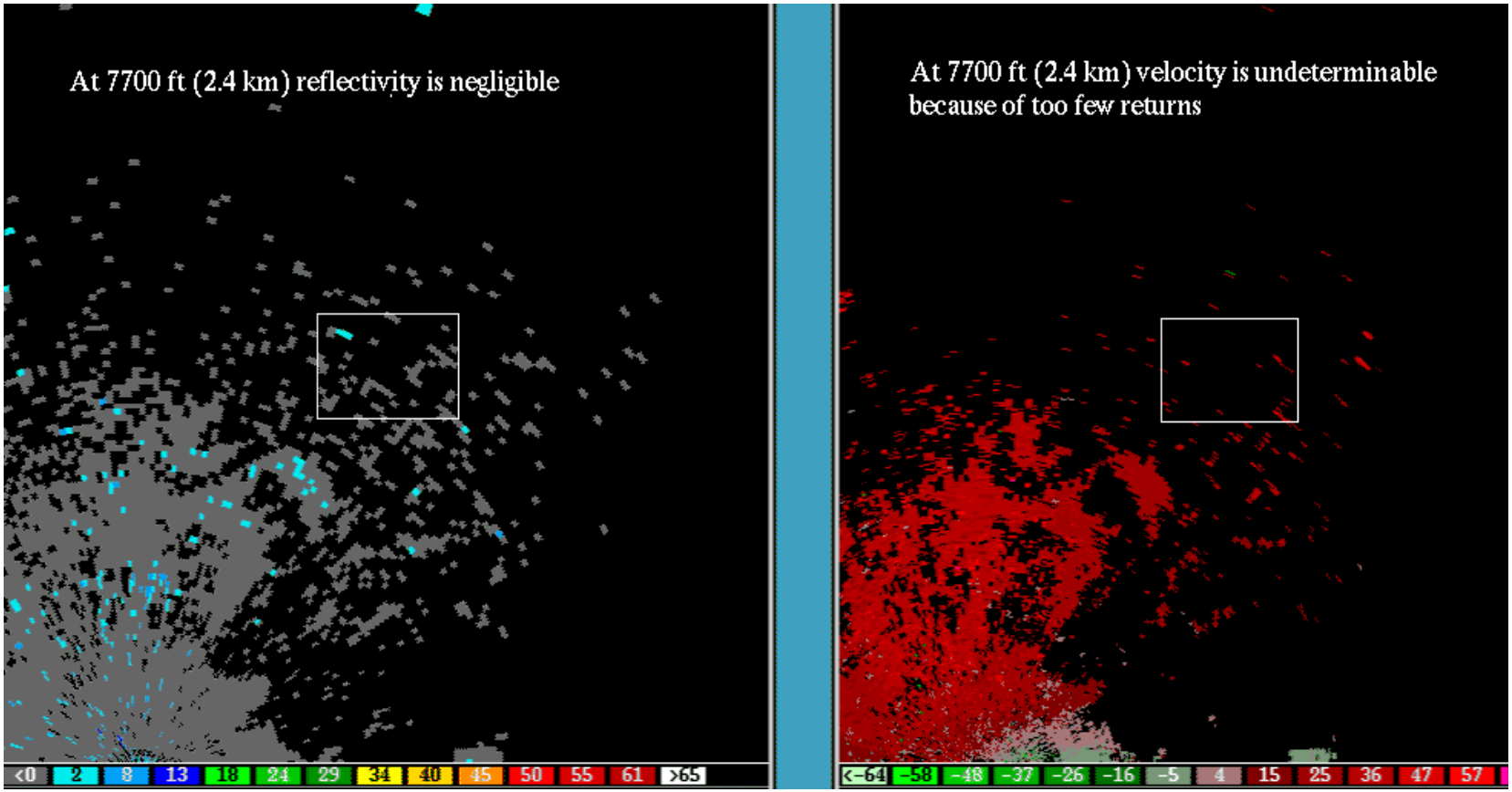






Case Study 5

- NEXRAD data at I + 1 minute
- Normal clear air returns



Case Study 5 Conclusions

- Deep convection / thunderstorms ruled out
- Aircraft heading directly into warm / moist southerly flow
- At or just above cloud deck
- Possible wind surge not detectable in radar data

Overall Conclusions

- Wide range of causes for in-flight turbulence from convection to the jet stream
- Upsets can be captured by DFDR data but explanations may remain elusive
- High resolution data can assist in determining cause in many instances
- Pilots should continue to adhere to well known thunderstorm and CAT avoidance rules-of-thumb.

Future Work

- Automated turbulence detection needs to integrate:
  - ground and airborne radar
  - thermodynamic and wind profiles
  - satellite data

- Systems to warn of turbulence using airborne radars need to use winds aloft information to determine region of hazard "down wind" of convective cells (Case 1)

Future Work

- **Fast update information sensors/systems needed to avoid rapidly developing convective cells (Case 3)**
  - **ASR9 and ARSR4 (Corridor Integrated Weather System)**
  - **High update rate convective initiation forecasts**

- **Convective forecast algorithms can facilitate convective turbulence avoidance**
  - **Terminal Convective Weather Forecast (TCWF)**
  - **Regional Convective Weather Forecast (RCWF)**
  - **National Convective Weather Forecast (NCWF)**